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Strengthen the adaptability of the ERTMS implementation

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Strengthen the adaptability of the ERTMS implementation

By

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Preface

Before you lies the thesis: *Strengthen the adaptability of the ERTMS implementation.* A worthwhile journey through the world of railways. While it marks the end of a period of life as university student, it also ignited a new interest for improving the railway industry. The last six months I examined numerous aspects of ERTMS and concluded that there are numerous aspects more to examine.

Adaptability is also the word that comes to mind when I think about all the substantive and mental support I received from my supervisors. While the first meetings, including the kick-off, luckily were face-to-face, we soon had to surrender to a digital world due to the COVID-19 pandemic. I am very thankful for the persistent, tireless and frequent support that my supervisors offered me!

The complex technicalities of ERTMS frequently led to various questions. Luckily, my company supervisor Gérard Hoeberigs always took the time to help me break through those complexities, resulting in numerous long discussions where all details were brought to the surface. To create insight in the complexities of ERTMS, I designed multiple models. Egidio Quaglietta, my daily supervisor, served as substantive and mental mainstay through all the concept versions needed. Furthermore, he enlightened me on all the ongoing initiatives and researches within the world of ERTMS. Besides the technicalities, I did research on the governance and stakeholder management surrounding ERTMS. My daily supervisor, Wijnand Veeneman, carried me through this process with patience. Furthermore, he sharpened my thoughts and helped me to have a scientific view. I also would like to thank Rob Goverde, the chair of my supervision team, for his time and guidance on key moments. With his feedback I elevated this research to a higher level.

I would like to thank my colleagues of the Ministry of Infrastructure and Water Management for their insight, distraction and the ability to participate in various ministerial processes. Furthermore, I would like to thank all of my respondents, without whose information I would not have been able to conduct this research. Also, I would like to thank my fellow students, Maurits, Frank, Maurits, Rogier and Eline for their welcome perspective and feedback during this process.

Finally, I would like to thank my family and girlfriend: Annette, Willemien, Willem Hendrik, Arend-Jan, Hermen, Nienke and Thirsa for their continuous support. Without their wise council and kind words, I would not have completed a university master's programme.

Gijsbert Westerhuis

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Summary

In Europe, transport and travelling cause almost 25% of the total greenhouse emissions. The modes that contribute most to this percentage are road transport and civil aviation. Furthermore, the use of these modes has increased tremendously in the past twenty years and this growth is expected to continue. To counteract this trend, the European Commission envisions a Europe in which the high-speed train is the standard transport mode for connecting cities. Two of the challenges to accomplish this goal is alignment and interoperability in Europe's rail infrastructure. The chosen solution for these challenges is the implementation of a standardised railway safety system called ERTMS (European Rail Traffic Management System).

ERTMS is a complex system that evolves continuously while countries, like the Netherlands, plan more than thirty years for its implementation. This introduces the risk of implementing outdated components. Due to these conditions, the system must be implemented in an adaptable manner. Adaptability is the ability of a system to meet technological or functional changes without requiring structural modifications or replacements. The Netherlands is currently in the midst of planning the implementation of ERTMS throughout its rail network with the need of adaptability becoming more apparent with changing needs of the system. This fortifies the societal need of this research. Furthermore, as this implementation process is found throughout Europe, with changing and rather unknown technological, operational, business and regulatory developments, the scientific gap is also apparent. With this, the main research question can be formulated:

"Which strategy can be chosen to strengthen the adaptability of the Dutch implementation of ERTMS to future rail operational needs?"

To create a structured and well-founded research, the main research question is split into several sub-questions. These are as follows:

1. Which factors influence adaptability?
2. Which parts or interfaces of ERTMS are prone to developments in the near future?
3. How can these factors be translated into solutions that strengthen the adaptability of ERTMS to future developments?
4. How does these solutions perform in a probable use case?

The first two sub-questions have the goal to define the meaning of adaptability to ERTMS. A literature review, case studies gather factors that influence adaptability. An ERTMS development analysis provides factors that gives insight in what components are prone to developments in the near future. The third sub-question is answered in an ERTMS adaptability analysis where the factors and issues are translated into proposed solutions that strengthen the adaptability of ERTMS. These solutions are then tested in a use case and validated by experts, answering the fourth sub-question. The solutions are integrated with the additional comments from the experts into a validated strategy which is given in the conclusion, thus providing an answer to the main research question.

Adaptability factors and critical issues for the implementation of ERTMS

Four chapters in this thesis are dedicated to deduct factors and issues that substantiate the formulation of the proposed solutions that strengthen the adaptability of ERTMS. These chapters

analyses literature, ERTMS, its future developments and three case studies. Each analysis deducts various factors or critical issues related to strengthening adaptability.

Adaptability factors are generalized factor that influences adaptability. Critical issues are criticalities in the current ERTMS implementation that might trigger adaptability and compatibility issues in the future with respect to technological, organizational, financial or regulatory developments.

These factors and issues are then merged based on their common ground into various factors that are given in Table 1. The literature review identifies adaptability factors from available literature on adaptability in transport planning, large migrations in infrastructure projects, the role of standardisation, implementation of technological innovations and the complexities on integrated management systems. The analysis of ERTMS basics provides information about its description, the Dutch migration process, its current stakeholders and migration processes of other countries. The ERTMS development analysis assesses the impact of several innovations on the Dutch implementation and provides critical issues for this. For confirmation of the factors gathered in the literature study, three case studies are performed: the HSL-Zuid project, the implementation of RouteLint and the implementation of the OV-Chipcard. For each case, besides using literature, various employees from the involved companies are interviewed to acquire knowledge about examples where adaptability was hindered or stimulated. Each case confirmed various adaptability factors. These factors are shown in Table 1.

Table 1: Summarised factors that influence adaptability

Factor	Description
Stakeholder involvement	The involvement of various different stakeholders increases sector-wide support for decisions thus decreases the need for adaptability.
Process clarity	Improving the clarity in the implementation process by providing information for preparation of stakeholders through road mapping or a simulator.
Leadership	Strong leadership ensures integrity and purpose in the process.
Flexibility management	Preserve the ability to change direction with respect to technology and governance.
Modularity	The ability to replace or implement components without requiring to modify existing components.
Standardisation	For interoperability, ensure standardisation in interfaces and components.
Operational compatibility	A technological implementation might also have an effect on operational aspects.
Technology updating	Necessary technological changes after implementation of components that contain errors.
Future needs	Requirements due to upcoming innovations.

ERTMS adaptability analysis

The adaptability factors and critical issues are translated into solutions that increases adaptability for the Dutch ERTMS implementation. These proposed solutions from the ERTMS adaptability analysis (chapter 6) are summarised in Table 2 according to the used categorization.

Table 2: Summarised proposed solutions provided from the ERTMS adaptability analysis (chapter 6).

Technological implementation		
Topic	***Critical issue***	**Proposed solution**
ERTMS baseline management	*ERTMS baseline updates are expected in the future but these standards are until now not fully compatible and experiences maturity issues.*	Choose a dominant standard and tender, using small regions and with transparency, with a new standard. This new standard must be considered mature enough and backwards compatibility is ensured.
ETCS application level management	*ETCS application levels have an effect on the requirements for necessary track and on-board components.*	Transparency is important in choosing the application level. Furthermore, let ETCS HL3 be a sector-wide driven innovation and include it in the official specifications.
Interface management	*ERTMS and its interfaces are continuously evolving with changing needs and possibilities.*	New interfaces must be enabled through modularity using standardisation and facade patterns.
Component management	*Required components of upcoming innovations could have overlap or incompatibility between them or with existing components.*	Prepare various components for the integration or cooperation with additional components. More information can be found in section 6.2.4
Governance and stakeholder management		
Topic	***Critical issue***	**Proposed solution**
Position program ERTMS	*The program is sensitive for the interests of a single or a selection of stakeholders.*	Balance stakeholder involvement by stimulating a diverse group of employees in the ERTMS program and give the means necessary for the program manager of Min I&W to function as central leader.
Stakeholder involvement	*Cooperation and coordination between stakeholders such as involved actors, experts and interest group or end users.*	Increase sector-wide support for decisions by involving stakeholders with informal interaction, a comprehensive roadmap, organized meetings and joint KPIs.
Generation of support	*Interconnection between stakeholders and support of ERTMS and upcoming innovations.*	Improve interconnection and support by appointing ambassadors, organizing meetings and creating visualizations.
Changeability in contract	*Decreased changeability due to contract setup or static policies.*	Preserve adaptability in the contract by rewarding changeability and by preserving flexibility in applicable policies.
Financial and regulatory adaptations		
Topic	***Critical issue***	**Proposed solution**
Availability of budget	*Marginal technological changes are considered expensive.*	Acquire sufficient budget to cover necessary marginal technological changes.
Certification	*Changing national values result in the necessity to entirely re-certifying vehicles.*	Change the certification approach by certifying a vehicle against a range of national values instead of only the applicable value.

Use case

The use case tests the proposed solutions in a real-world example. The implications are analysed and validated by three experts. The chosen corridor is Kijfhoek – Roosendaal where FRMCS-only is implemented using a new TSI. This development is put through after that this corridor is implemented with ERTMS according to the planned Dutch implementation amended with the proposed solutions. The validated implications are categorized in the same manner as in the previous chapter: technological implications, implications for governance and stakeholder management and implications from the financial and regulatory adaptations.

The technical implications indicate that the main shortcoming of the proposed solutions is the restraint of the signalling industry to sell components that are prepared for new innovations without official specifications. Draft documents are conceived as insufficient. For this reason, the solution to establish a modular system is important. A modular system improves, through standardisation and facade patterns, adaptability of corresponding components.

The implications for governance and stakeholder management indicate that the main shortcoming of the proposed solutions is the absence of the use of the entire range of instruments available to provide a good governance and stakeholder management. Involvement and transparency is endorsed but could prove ineffective when not combined with firm and proper use of instruments such as regulations and obligations. The main endorsement is the creation of a comprehensive roadmap that provides information on the various aspects of the Dutch ERTMS implementation.

Finally, the interviewed ERTMS expert introduced the negative effect of technical national rules on adaptability in addition of the already specified national values. In short, an update of the on-board equipment can imply that this equipment must meet various additional, newly established rules of other European countries. This decreases the business case for each update.

Conclusion and recommendations

The final section in this thesis provides an answer on the main research question by providing a validated strategy for strengthening the adaptability of the Dutch ERTMS implementation for future rail operational needs. As with the previous two sections, the strategy is divided in three topics concerning technology, governance and stakeholder management and financial and regulatory adaptations.

To increase technical adaptability, various measures are advised. First, ERTMS baseline management should be clear and transparent by selecting B3R2 as dominant standard with the possibility to update to another TSI if maturity and backwards compatibility is ensured and if tendered in small regions. Second, a clear and transparent ETCS application level management should be executed by including stakeholders in the process of implementing ETCS L2 with preparation towards ETCS HL3 and including ETCS HL3 into the official TSI. Third, ERTMS should be implemented to allow interfacing with and integration of components required by upcoming innovations. Adaptability is improved with the establishment of a modular system through standardisation and facade patterns.

To increase adaptability with respect to governance and stakeholder management, various measures are advised. First, all roles in the governance model must be properly fulfilled enforced by the firm and proper use of the entire range of regulatory instruments that are available for the Ministry. Second, stakeholders must be involved to increase cooperation and coordination using various methods, but especially with the creation of a comprehensive roadmap that includes planning, status and new innovations. Third, support should be generated with various methods to increase interconnection and reduce the negative effect of arising issues. Fourth, changeability should be inserted in the contract by rewarding instead of penalizing it.

To increase adaptability with respect to financial and regulatory aspects, various measures are advised. First, to free sufficient budget to deal with required marginal technological changes. Second, to be aware of the effect that changing national values or national technical rules could have on ETCS on-board equipment.

The summarised recommendations for further research are:

- Research into a realistic creation of a comprehensive roadmap that contains information on planning, status and upcoming innovations.
- Research into the establishment of modularity of components necessary or affected by upcoming innovations.
- Research into the effects of the researched innovations on the Dutch implementation of ERTMS based upon official documentation.
- Research into the effect of national values and national technical rules on ETCS on-board equipment.

Samenvatting

In Europa veroorzaken vervoer en reizen bijna 25% van de totale broeikasgasemissies. De modaliteiten die het meest bijdragen aan dit percentage zijn het wegvervoer en de burgerluchtvaart. Bovendien is het gebruik van deze modaliteiten de afgelopen twintig jaar enorm toegenomen en zal deze groei de komende jaren naar verwachting verder toenemen. Om deze trend tegen te gaan, heeft de Europese Commissie een Europa voor ogen waarin de hogesnelheidstrein de standaard wordt voor het verbinden van steden. Twee van de uitdagingen om dit doel te bereiken zijn afstemming en interoperabiliteit in de Europese spoorweginfrastructuur. De gekozen oplossing voor deze uitdaging is de implementatie van een gestandaardiseerd beveiligingssysteem genaamd ERTMS (European Rail Traffic Management System).

ERTMS is een complex systeem dat continu evolueert, terwijl landen zoals Nederland meer dan dertig jaar plannen voor de implementatie. Dit introduceert een risico dat achterhaalde componenten worden geïmplementeerd. Vanwege deze omstandigheden moet het systeem op een adaptieve wijze worden geïmplementeerd. Adaptiviteit is het vermogen van een systeem om te voldoen aan technische of functionele veranderingen zonder dat structurele aanpassingen of vervangingen nodig zijn. Nederland is momenteel bezig met het plannen van de implementatie van ERTMS op het gehele spoorwegnet, waarbij de noodzaak voor adaptiviteit steeds duidelijker wordt naarmate de randvoorwaarden van het systeem veranderen. Dit versterkt het maatschappelijke nut van dit onderzoek. Aangezien dit implementatieproces in heel Europa wordt uitgevoerd met veranderende en tamelijk onbekende technologische, operationele, organisatorische en beleidstechnische ontwikkelingen, is ook het wetenschappelijke nut helder. Hiermee kan de hoofdvraag worden geformuleerd:

“Welke strategie kan worden gekozen om het aanpassingsvermogen van de Nederlandse implementatie van ERTMS voor toekomstige operationele spoorbehoeften te versterken?”

Om tot een gestructureerd en gefundeerd onderzoek te komen, wordt de hoofdvraag opgesplitst in verschillende deelvragen. Dit zijn de volgende:

1. Welke factoren beïnvloeden adaptiviteit?
2. Welke onderdelen of interfaces van ERTMS zijn vatbaar voor ontwikkelingen in de nabije toekomst?
3. Hoe kunnen deze factoren worden vertaald in oplossingen die de adaptiviteit van ERTMS voor toekomstige ontwikkelingen versterken?
4. Hoe presteren deze oplossingen in een waarschijnlijke use-case?

De eerste twee deelvragen hebben tot doel de betekenis van adaptiviteit voor ERTMS te definiëren. Zowel de literatuurstudie als de onderzochte casussen verzamelen factoren die adaptiviteit beïnvloeden. Een analyse van de ontwikkelingen van ERTMS geeft factoren die inzicht geven in welke componenten of koppelingen gevoelig zijn voor ontwikkelingen in de toekomst. De derde deelvraag wordt beantwoord in een ERTMS adaptiviteitsanalyse waar de factoren en kritieke punten worden vertaald in voorgestelde oplossingen die adaptiviteit van ERTMS versterken. Deze oplossingen worden vervolgens getest in een use-case en gevalideerd door experts, waarbij de vierde deelvraag wordt beantwoord. De oplossingen worden geïntegreerd met de aanvullende opmerkingen van de experts

in een gevalideerde strategie. Deze strategie is gegeven in de conclusie waarmee ook een antwoord gegeven is op de hoofdvraag.

Adaptiviteitsfactoren en kritieke punten voor de implementatie van ERTMS

Vier hoofdstukken in deze scriptie zijn gewijd aan het verzamelen van factoren en kritieke punten die als onderbouwing fungeren voor de voorgestelde oplossingen die adaptiviteit van ERTMS versterken. Deze hoofdstukken analyseren de literatuur, ERTMS, bijbehorende ontwikkelingen en de drie casussen. Elke analyse verzamelt verschillende factoren of kritische punten die verband houden met het versterken van adaptiviteit. Adaptiviteitsfactoren zijn generieke factoren die adaptiviteit beïnvloedt. Kritieke punten zijn punten in de huidige ERTMS implementatie die in de toekomst aanpassings- en compatibiliteitsproblemen kunnen veroorzaken met betrekking tot technologische, organisatorische, financiële of regelgevende ontwikkelingen. Deze worden vervolgens op basis van hun raakvlak samengevoegd tot verschillende factoren die in Tabel 1 worden weergegeven. Het literatuuronderzoek leidt factoren af van beschikbare literatuur over adaptiviteit in transportplanning, grote migraties in infrastructuurprojecten, de rol van standaardisatie, implementatie van technologische innovaties en de complexiteit van geïntegreerde beheersystemen. De analyse van de basis van ERTMS geeft informatie over de omschrijving van ERTMS, het Nederlandse migratieproces, de huidige stakeholders en migratieprocessen van andere landen. De analyse over de ERTMS ontwikkelingen onderzoekt het effect van verschillende innovaties op de Nederlandse implementatie van ERTMS waarbij bijbehorende kritieke punten worden beschreven. Ter bevestiging van de factoren uit het literatuuronderzoek worden drie casussen onderzocht. De casussen zijn: het project HSL-Zuid, de implementatie van RouteLint en de implementatie van de OV-Chipkaart. Per casus worden, naast het gebruik van literatuur, verschillende medewerkers van de betrokken bedrijven geïnterviewd om kennis op te doen over voorbeelden waar adaptiviteit werd belemmerd of gestimuleerd. Elke casus bevestigt verschillende adaptiviteitsfactoren. Deze factoren worden weergegeven in Tabel 1.

Tabel 1: Samengevatte factoren die adaptiviteit beïnvloeden

Factoren	Samengevatte adaptiviteitsfactoren en kritieke punten
Betrokkenheid van belanghebbenden	De betrokkenheid van verschillende belanghebbenden vergroot de sector-brede ondersteuning van beslissingen en vermindert zo de behoefte voor adaptiviteit.
Proces verduidelijking	Het verbeteren van de duidelijkheid van het implementatieproces door informatie te verstrekken voor de voorbereiding van belanghebbenden door middel van road mapping of een simulator.
Leiderschap	Sterk leiderschap zorgt voor integriteit en doelgerichtheid in het proces.
Flexibiliteitsbeheer	Het behoud van het vermogen om van richting te veranderen met betrekking tot technologie en organisatie.
Modulariteit	De mogelijkheid om componenten te vervangen of te implementeren zonder bestaande componenten te hoeven wijzigen.
Standaardisatie	Zorg voor interoperabiliteit via standaardisatie in interfaces en componenten.
Operationele compatibiliteit	Een technologische implementatie kan ook effect hebben op operationele aspecten.
Updaten van technologie	Noodzakelijke technische wijzigingen na implementatie van componenten die fouten bevatten.
Toekomstige benodigdheden	Vereisten als gevolg van aankomende innovaties.

ERTMS-adaptiviteitsanalyse

De genoemde adaptiviteitsfactoren en kritische punten worden vertaald in oplossingen die de adaptiviteit voor de Nederlandse ERTMS-implementatie versterkt. De voorgestelde oplossingen uit de adaptiviteitsanalyse van ERTMS (hoofdstuk 6) zijn samengevat in Tabel 2 volgens de gebruikte indeling.

Tabel 2: Samengevatte, voorgestelde oplossingen uit de ERTMS-adaptiviteitsanalyse (hoofdstuk 6).

Technologische implementatie		
Thema	***Kritiek punt***	**Voorgestelde oplossing**
ERTMS baseline beheer	*ERTMS baseline updates worden in de toekomst verwacht, maar deze standaarden zijn tot nu toe niet volledig compatibel en ondervinden volwassenheidsproblemen.*	Kies een dominante standaard en start een aanbesteding in kleine regio's, met transparantie en met een nieuwe standaard. Deze nieuwe standard moet als volwassen genoeg wordt beschouwd en achterwaartse compatibiliteit moet worden gegarandeerd.
ETCS toepassingsniveau beheer	*ETCS-toepassingsniveaus hebben een effect op de vereisten voor noodzakelijke baan- en treincomponenten.*	Transparantie is belangrijk bij het kiezen van het toepassingsniveau. Laat ETCS HL3 bovendien een sector-brede gedreven innovatie zijn en voeg deze aan de officiële specificaties toe.
Interface beheer	*ERTMS en mogelijke interfaces evolueren voortdurend met veranderende behoeften en mogelijkheden.*	Nieuwe interfaces moeten mogelijk worden gemaakt door modulariteit met behulp van standaardisatie en facadepatronen.
Component beheer	*Vereiste componenten van aankomende innovaties kunnen overlappen tussen deze of met bestaande componenten.*	Bereid verschillende componenten voor op de integratie of samenwerking met aanvullende componenten. Meer informatie kan gevonden worden in sectie 6.2.4.
Organisatie en stakeholdermanagement		
Thema	***Kritiek punt***	**Voorgestelde oplossing**
Positie programma ERTMS	*Het programma is gevoelig voor de belangen van een enkele of een selectie van belanghebbenden.*	Breng de betrokkenheid van belanghebbenden in evenwicht door een diverse groep werknemers in het ERTMS-programma te stimuleren en de middelen te verschaffen die de programmamanager van Min I&W nodig heeft om als centrale leider te functioneren.
Betrokkenheid van belanghebbenden	*De samenwerking en coördinatie tussen belanghebbenden zoals betrokken actoren, experts en belangenvereniging of eindgebruikers.*	De sector-brede ondersteuning van beslissingen vergroten door belanghebbenden te betrekken in informele interactie, een uitgebreide roadmap, georganiseerde vergaderingen en gezamenlijke KPI's.
Vergroten van steun	*De connectie tussen belanghebbenden en ondersteuning van ERTMS en aankomende innovaties.*	Verbeter connectie en ondersteuning door het aanstellen van ambassadeurs, organiseren van meetings en creëren van visualisaties.
Veranderbaarheid in het contract	*Verminderde veranderlijkheid als gevolg van de opzet van het contract of van statisch beleid.*	Behoud het aanpassingsvermogen in het contract door veranderlijkheid te belonen en door flexibiliteit in het bijbehorende beleid te behouden.
Financiële en wettelijke aanpassingen		
Thema	***Kritiek punt***	**Voorgestelde oplossing**
Beschikbaarheid van budget	*Marginale technologische wijzigingen worden als duur beschouwd.*	Voldoende budget verwerven om noodzakelijke marginale technologische wijzigingen te dekken.
Certificatie	*Veranderende nationale waarden leiden tot de noodzaak om voertuigen volledig opnieuw te certificeren.*	Wijzig de certificeringsbenadering door een voertuig te certificeren op basis van een reeks nationale waarden in plaats van alleen de toepasselijke waarde.

Use-case

De use-case test de voorgestelde oplossingen in een praktijkvoorbeeld. De implicaties worden geanalyseerd en gevalideerd door drie experts. Het gekozen baanvak is Kijfhoek - Roosendaal waar FRMCS-only wordt geïmplementeerd met een nieuwe TSI. Deze ontwikkeling is doorgezet waarna deze corridor is geïmplementeerd met ERTMS volgens de geplande Nederlandse implementatie welke is aangepast met de voorgestelde oplossingen. De gevalideerde implicaties zijn op dezelfde manier gecategoriseerd als in het vorige hoofdstuk: technologische implementatie, organisatie en stakeholdermanagement en financiële en wettelijke aanpassingen.

De technische implicaties geven aan dat de belangrijkste tekortkoming van de voorgestelde oplossingen de terughoudendheid van de industrie is om componenten te verkopen die zijn voorbereid op nieuwe innovaties zonder officiële specificaties. Conceptdocumenten worden als onvoldoende gezien. Om deze reden is de oplossing om een modulair systeem op te zetten belangrijk. Een modulair systeem verbetert, door standaardisatie en facadepatronen, de adaptiviteit van overeenkomstige componenten.

De implicaties voor organisatie en stakeholdermanagement geven aan dat de belangrijkste tekortkoming van de voorgestelde oplossingen is het ontbreken is van het gebruik van het hele scala aan beschikbare instrumenten. Deze instrumenten kunnen zorgen voor goede organisatie en stakeholdermanagement. Betrokkenheid en transparantie worden onderschreven, maar kunnen ineffectief blijken te zijn wanneer ze niet worden gecombineerd met stevig en correct gebruik van instrumenten zoals voorschriften en verplichtingen. De belangrijkste onderschrijving is de totstandkoming van een uitgebreide roadmap met informatie over de verschillende aspecten van de Nederlandse ERTMS implementatie.

Ten slotte introduceerde de geïnterviewde ERTMS-expert het negatieve effect van technische nationale regels op de adaptiviteit naast de reeds gespecificeerde nationale waarden. Kortom, een update van de boordapparatuur kan betekenen dat deze apparatuur moet voldoen aan diverse aanvullende, nieuw opgestelde regels van andere Europese landen. Dit vermindert de business case voor elke update.

Conclusie en aanbevelingen

Het laatste deel van deze scriptie geeft een antwoord op de hoofdvraag door een gevalideerde strategie te beschrijven voor het versterken van de adaptiviteit van de Nederlandse ERTMS-implementatie voor toekomstige operationele spoorbehoeften. Net als bij de vorige twee hoofdstukken is de strategie onderverdeeld in drie onderwerpen met betrekking tot technologie, organisatie en stakeholdermanagement en financiële en wettelijke aanpassingen.

Om de technische adaptiviteit te versterken worden verschillende maatregelen geadviseerd. Ten eerste moet ERTMS-baselinebeheer duidelijk en transparant zijn door B3R2 als dominante standaard te selecteren met de mogelijkheid om bij te werken naar een andere TSI als de volwassenheid en achterwaartse compatibiliteit is gegarandeerd en indien aanbesteed in kleine regio's. Ten tweede moet er een duidelijk en transparant beheer van ETCS-toepassingsniveau worden uitgevoerd door belanghebbenden te betrekken bij de implementatie van ETCS L2 met voorbereiding op ETCS HL3 en het toevoegen van ETCS HL3 aan de officiële TSI. Ten derde moet ERTMS worden geïmplementeerd om een interface met en een integratie van componenten die nodig zijn voor toekomstige innovaties mogelijk te maken. De adaptiviteit wordt versterkt door het opzetten van een modulair systeem door standaardisatie en facadepatronen.

Om adaptiviteit met betrekking tot organisatie en stakeholdermanagement te versterken worden verschillende maatregelen geadviseerd. Ten eerste moeten alle rollen in het organisatiemodel naar behoren worden vervuld en afgedwongen door een stevig en correct gebruik van het hele scala aan instrumenten dat beschikbaar is voor het ministerie. Ten tweede moeten belanghebbenden worden betrokken om de samenwerking en coördinatie te vergroten met behulp van verschillende methoden, maar vooral met het opstellen van een uitgebreide roadmap met planning, status en nieuwe innovaties. Ten derde moet er ondersteuning worden gegenereerd met verschillende methoden om de connectie te vergroten en het negatieve effect van problemen op de implementatie te verminderen. Ten vierde moet veranderlijkheid in het contract worden opgenomen door te belonen in plaats van het te bestraffen.

Om adaptiviteit ten opzichte van financiële en wettelijke aspecten te vergroten, worden verschillende maatregelen geadviseerd. Ten eerste om voldoende budget vrij te maken om de vereiste marginale technische wijzigingen te kunnen dekken. Ten tweede, zich bewust zijn van het effect dat veranderende nationale waarden of nationale technische regels zouden kunnen hebben op ETCS-boordapparatuur.

De samengevatte aanbevelingen voor verder onderzoek zijn:

- Onderzoek naar een realistische en gedetailleerde roadmap met informatie over planning, status en aankomende innovaties.
- Onderzoek naar het vaststellen van modulariteit van componenten die nodig zijn of beïnvloed worden door opkomende innovaties.
- Onderzoek naar de effecten van de onderzochte innovaties op de Nederlandse implementatie van ERTMS op basis van officiële documentatie.
- Onderzoek naar het effect van nationale waarden en nationale technische regels op ETCS-boordapparatuur.

Content

Glossary

Adaptability	The ability of a system to meet technological or functional needs without requiring structural modifications or replacements
Adaptability factor	A generalized factor that influence adaptability.
Critical issue	Criticalities in the current ERTMS implementation that might trigger adaptability and compatibility issues in the future.
ABE	Automatische Bediening ETIS (Automatic control ETIS)
ABT	Automatische Bediening TROTS (Automatic control TROTS)
ARI	Automatische Rijweg instelling (Automatic Route Setting)
ASTRIS	Aansturing en Status melding van de RailInfraStructuur (Control and status notification of the rail infrastructure)
ATB	Automatische treinbeïnvloeding (Automatic Train Protection)
ATO	Automatic Train Operation
ATP	Automatic Train Protection
B2	Baseline 2
B3	Baseline 3
B3MR1	Baseline 3 Maintenance Release 1
B3R2	Baseline 3 Release 2
BIU	Brake Interface Unit
BTM	Balise Transmission Module
CAS	Complex Adaptive System
CBS	Centraal Bureau voor Statistiek (Bureau of Statistics Netherlands)
CBTC	Communication-Based Train Control
CCS	Control Command and Signalling
CIO	Chief Information Officer
CR	Change Requests
CSS	Central Safety System
DAS	Driver Advisory System
C-DAS	Connected Driver Advisory System
N-DAS	Networked Driver Advisory System
S-DAS	Standalone Driver Advisory System
DBFM	Design, Build, Finance and Maintain
DMI	Driver Machine Interface
DO	Directeurenoverleg (Directors Meeting)
EC	European Commission
ECF	Eigenstandige controle functie (Independent Control Officer)
EOR	European Operating Rules
ERA	European Railway Agency
ERRAC	European Rail Research Advisory Council
ERTMS	European Rail Traffic Management System
ETCS	European Train Control System
ETCS L1-L3	European Train Control System Application Level 1 t/m 3
ETCS HL3	European Train Control System Hybrid Application Level 3
ETIS	Electronic Train Information System
ETML	European Train Management Layer
EUG	ERTMS Users Group
EULYNX	Consortium of European Infrastructure Managers
EVC	European Vital Computer
Facade pattern	A structural layer allowing systems to be loosely coupled such that either system is little affected by changes beyond this layer.
FRMCS	Future Railway Mobile Communication System
GoA	Grade of Automation
GSM-R	Global System for Mobile Communications – Rail
HMI	Human Machine Interface (see DMI)
HSL-Zuid	Hogesnelheidslijn (High-Speed Line between Schiphol and Belgium)

IM	Infrastructure Manager
IMS	Integrated Management System
IXL	Interlocking
KPI	Key Performance Indicators
LEU	Lineside Electronic Unit
MA	Movement Authority
Min I&W	Ministry of Infrastructure and Water Management
Modes	
FS	Full Supervision mode
LS	Limited Supervision mode
OS	On Sight mode
SH	Shunting mode
SR	Staff Responsible mode
SN	National System mode
MoU	Memorandum of Understanding
NS	Nederlandse Spoorwegen (Dutch National rail operator)
OBU	On-board Unit
OCORA	Open CCS On-board Reference Architecture
PBO	Programma Beheersingsoverleg (Program Manage Meeting)
RCA	Reference CCS Architecture
PLC	Programmable Logic Controller
RU	Railway Undertaking
PRL	Procesleiding (Process Management)
RBC	Radio Block Centre
SIL	Safety Integrity Level
SRS	System Requirements Specification
STM	Specific Transmission Module
SysML	System Modelling Language
T2T	Train-to-train
TCS	Traffic Control System
TIM	Train Integrity Monitoring
TIU	Train Interface Unit
TLS	Translink Systems
TMS	Traffic Management System
TROTS	TRein Observatie & Tracking Systeem (Train observation and tracking system)
TSI	Technical Specifications for Interoperability
UIC	Union internationale des chemins de fer (International union of railways)
UML	Unified Modelling Language
UNIFE	Union des Industries Ferroviaires Européennes (The Association of the European Rail Industry)
UNISIG	UNIFE ETCS Working group
V2V	Vehicle-to-Vehicle
VC	Virtual Coupling
VL	Verkeersleiding (Traffic Management)
VOS	Verkeersleiding Ondersteunend Systeem (Traffic Management Support System)

1. Introduction

This introduction provides insight on the subject of this thesis. Section 1.1 starts by describing the project context and section 1.2 will zoom in on the research problem. Both these sections describe the societal and scientific gap. The following section (1.3) will summarize the first two sections in the main research question and following sub-questions. Section 1.4 describes the methodology which is used throughout this thesis to construct an answer on the research questions. Section 1.5 will set the scope for this thesis in order to make it feasible. Finally, section 1.6 will provide information about the outline of this thesis and describes this in a reading guide.

1.1 Project context

The debate about climate change is very strong. The emissions which are caused by transport are part in this climate change debate. In Europe, transport and travelling cause almost 25% of the total greenhouse emissions (Eurostat, 2019). In the Netherlands, the transport sector contributes up to 19% to the CO2 emissions (CBS, 2019). The modes that contribute most to this percentage are road transport and civil aviation. Furthermore, car and airplane use has increased tremendously in the past twenty years and this growth is expected to increase further in the next years (CBS, 2018; Rosen, 2017). To counteract this trend, the European Commission envisions a Europe in which the high-speed train is the standard transport mode for connecting cities (EC, 2016; ERRAC, 2007). The vision formulated in 2007 aims to increase the usage of the rail network by increasing its quality. Seven research areas are formulated which can contribute to this quality improvement.

One of these areas is focused on the infrastructure and its interoperability across European member states. The main goal is to implement a standardised railway safety system which enables rolling stock to run throughout Europe without coming across unidentifiable systems and thus obstructing its passage. This standardised system is called the European Rail Traffic Management System (ERTMS). The migration towards this system is very complex and requires, in practice, much time. While Belgium, as first country, made the political decision to migrate parts of their system towards ERTMS in 2001 and started its deployment in 2009 (Jarašūnienė, 2005; EC, 2017), the infrastructure manager of the Netherlands foresees that the Dutch implementation process is completed around 2050 (Prorail, 2019). If the system implemented in 2050 is identical to the one deployed in 2009, then this system is likely of being outdated when fully implemented. According to the vision formulated by the European Rail Research Advisory Council in 2017, the migration towards ERTMS should facilitate adaptations to business challenges while supporting future state-of-the-art technologies like track and vehicle sensors, 5G or quantum computing (ERRAC, 2017).

Adaptability
In this thesis, adaptability is explained as follows: adaptability is the ability of a system to meet technological or functional needs without requiring structural modifications or replacements. A good adaptability of a system enables the support of recent developments within that deployed system, instead of being unable to adapt from an outdated component to a newly developed and better performing component due to the necessary structural changes.

1.2 Research problem

As described in section 1.1, the implementation of ERTMS should be able to adapt to developments in technological and organisational areas. The current Dutch rail innovation agenda is focussed on implementing a standardised ERTMS specification on various existing or new rail corridors within the Netherlands (Min I&M, 2013). However, on the corridors where ERTMS is already implemented, its system and implementation is specially developed for specific needs, which decreases the ability to further adapt to new developments. This is mainly due to standing contracts which creates a vendor lock-in (see section 5.1). However, technological reasons also play a role. When the implementation started, the envisioned system did change continuously due to also changing operational needs. This fortifies the needs for adaptability of the implementation of ERTMS (Min I&M, 2014).

However, this could create a contrast between goals. While there is a need for adaptability, the main point of ERTMS is alignment and interoperability between European member states. An increased adaptability must not decrease the interoperability of the system. The goal of this thesis is to investigate where adaptability can be strengthened while maintaining its interoperable basis. The Netherlands and its implementation of ERTMS is chosen as focus within this thesis. The Dutch railway network is the busiest within the European Union making the migration towards ERTMS critically vulnerable (CBS, 2009, 2016). The Netherlands are currently in the midst of planning the implementation of ERTMS throughout its rail network with the need of adaptability becoming more apparent with changing needs for the system (ProRail, 2019; Min I&M, 2013). This fortifies the societal need of this research. Furthermore, as this implementation process is done by multiple European member states with changing and rather unknown technological, operational, business and regulatory developments the scientific gap is also apparent.

1.3 Research question

Following the scientific and societal gap described in sections 1.1 and 1.2, the main research question can be formulated:

"Which strategy can be chosen to strengthen the adaptability of the Dutch implementation of ERTMS to future rail operational needs?"

To create a structured and well-founded research, the main research question is split into several sub-questions. These are as follows:

1. Which factors influence adaptability?
2. Which parts or interfaces of ERTMS are prone to developments in the near future?
3. How can these factors be translated into solutions that strengthen the adaptability of ERTMS to future developments?
4. How does these solutions perform in a probable use case?

How these research questions fit within the outline of this thesis can be found in section 1.6.

1.4 Methodology

This thesis introduces the term adaptability factor as a generalized factor that influence adaptability. Critical issues are criticalities in the current ERTMS implementation that might trigger adaptability and compatibility issues in the future with respect to technological, organizational, financial or regulatory developments. In order to provide an answer to the research question, six steps are taken. These methodological steps are described in this section. The first step is the review of available literature. This review provides factors that influence adaptability, which are used to evaluate the ERTMS implementation and the case studies. Also, the review provides the information required throughout the thesis. The second step is to conduct stakeholder interviews, which provide information where the literature review proves to have inadequate information for the required goal. For instance on the validation of the conceptual model and providing further information on the three case studies. Furthermore, the stakeholder interviews are used to validate the use case. The third step is the scenario analysis, which is used to assess future developments for ERTMS applicability. The fourth step consists of three case studies that confirms the factors deducted by the literature study. The fifth step is to make a comprehensive model of the Dutch ERTMS implementation and a variation for each foreseen innovation. This provides insight in the effects of future challenges of ERTMS applicability and identifying critical issues of ERTMS. The sixth and final step is the use case, which is used to assess the effectiveness of the formulated solutions by testing the adapted ERTMS implementation in a metaphorical scenario. These steps are visualised in Figure 1. Furthermore, an additional explanation of the steps can be found in Appendix B.

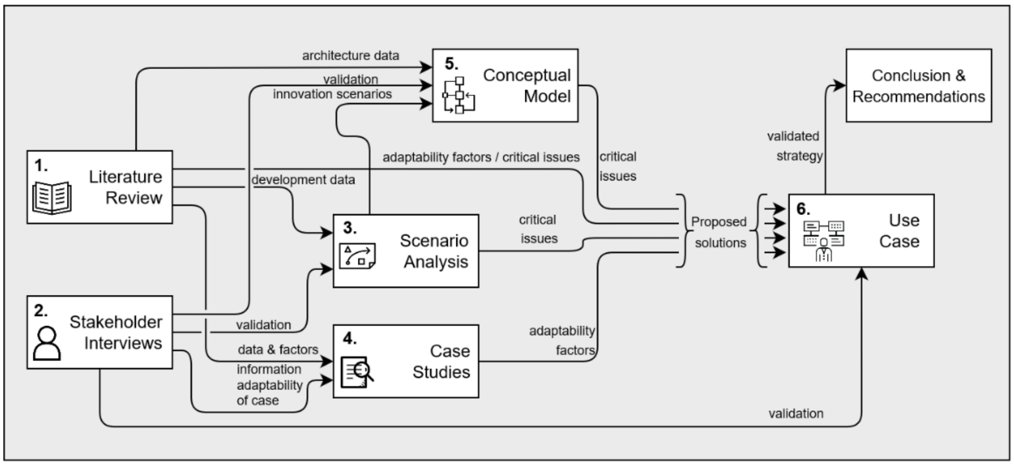

Figure 1: The six steps visualized

1.5 Scope

As this thesis is focussed on a current large European rail-migration, it consists of many different aspects that could change throughout the research period. It is therefore important to set clear boundaries to scope this research. The first aspect is that this thesis focusses on the Dutch implementation of ERTMS. While other countries are analysed in chapter 3, the solutions are formed towards the Dutch implementation of ERTMS. The second aspect is the limitation of the number of interfaces which are taken into account. The limitation is based on an evaluation of the interfaces on probability of execution within the chosen time scale and the current configurability within the Dutch implementation of ERTMS. The third aspect is the time scale which is taken into account. This is split into two parts. The first part is the limitation of the general time scale until 2050. The integrated strategy should be feasible until at least this year. However, potential interfaces and challenging trends in ERTMS applicability which are probable to occur before 2035 are considered. After 2035, the level of uncertainty within technological and organisational trends is too high. The fourth aspect is the focus in gathering of the data. All steps in the methodology are executed to provide an advice on the provided research question. For example, only the factors that could stimulate or hinder the adaptability in the Dutch implementation of ERTMS which result from the literature review, the scenario analysis and the case studies are analysed in depth. The fifth and final aspect is that, due to its unpredictability, the effects of the COVID-19 pandemic on public transport are not taken into account in this thesis.

1.6 Reading guide

This section will provide an outline for this thesis, which is visualized in Figure 2. The thesis starts with an introduction on the subject. This will be done by describing the project context, the research problem, the research questions, the scope and the methodology. Thus, legitimating the research. Chapter 2 will provide a literature review on various subjects surrounding adaptability identifying adaptability factors. Chapter 3 will provide an overview of the basics surrounding ERTMS. This consists of a general and technical description, the Dutch migration process, its current stakeholders and migration processes of other countries further providing critical issues. Chapter 4 performs an analysis on the future developments of ERTMS. To gain insight in the effects, future innovations are modelled. With this, various factors in the form of critical issues of the Dutch ERTMS implementation can be identified. Chapter 5 will describe three case studies, in which the evaluation of technology implementation provides confirmation for the factors gathered in the literature review. Chapter 6 will translate the identified adaptability factors and critical issues into a list of proposed solutions that can strengthen the adaptability of ERTMS. Chapter 7 will test these proposed solutions in a use case which is validated by three experts with different fields of expertise. Chapter 8 will conclude the thesis by providing an integrated and validated strategy and recommendations for further research.

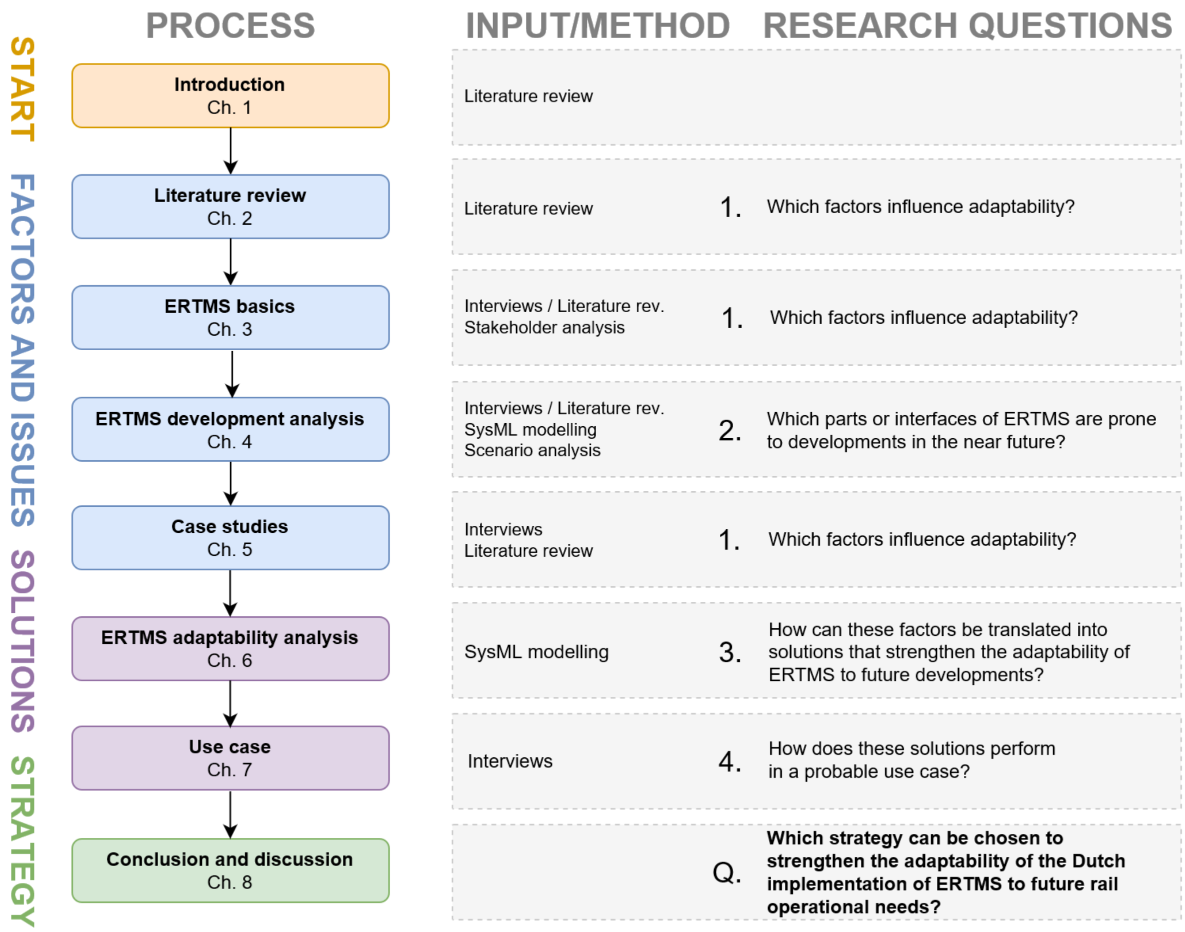

Figure 2: Outline of the thesis

2. Literature review

This chapter reviews literature to identify factors that could stimulate or hinder adaptability. This is done by researching scientific articles on adaptability in transport planning (section 2.1), large migrations in infrastructure projects and the role of standardisation (section 2.2), the implementation of technological innovations (section 2.3) and complexities on integrated management systems (section 2.4). By scanning these articles, adaptability factors are gathered that are summarized in section 2.5.

2.1 Adaptability in transport planning

How to deal with uncertainty in transport planning and policy making is a subject that is treated extensively in literature. However, the way in which uncertainty is addressed changed in the last thirty years. While Khan (1989) argued that transport planners were urged to view forecasts with a lot of caution and that rigid transportation plans with a horizon of more than 20 years should not be seen as realistic, Navarro et al. (2019) suggest that the uncertainty issue can be addressed in a heuristic framework that prevents uncertainty dimensions to be too elusive or meaningless. Lyons & Davidson (2016) even suggest that uncertainty is an opportunity for decision makers to realise that they are shaping the future instead of only reacting to a prediction. Another method to address uncertainty is with adaptability and flexibility of transportation policy and planning (Gifford, 1994). Gifford (1994) argued that the occurrence of apparent predictable travel behaviour and therefore the needs in a transportation system is merely transitory. Therefore he conceptualized the challenge for the infrastructure planning community to adapt to uncertainty. Salet et al. (2013) further builds upon this argument and provides four pointers in how to proceed in uncertainty. First that the strategic mission is deliberately framed with the possibility to be reframed. Second the mobilization of institutional capacity, or including groups within the process. Third the identification of robust policy options. These options enables flexibility in uncertainty. Finally a simulation must be set-up to test the effect of possible operational choices and thus creating a learning environment (Salet et al., 2013).

Adaptability can be implemented in various ways having various goals. This can range from adaptability of the decision-making process to a society demanding involvement (Zembri & Campagnac, 2014). The importance to have considerable attention to reducing risks and uncertainties and the ability to adapt to new information (Maromachi et al., 2014). Also the importance of alignment between actors so that uncertainty can be dealt with more easily (Giezen et al., 2014).

Uncertainty is a constant within the transport sector, that much is clear. However, policy makers often make static decisions and policies based on the notion that all decisions are made at one single point in time based on the current available data (Ramjerdi & Fearnley, 2014). Ramjerdi & Fearnley (2014) argue that, due to the complexities of transportation systems, it is preferred to address unintended effects when they occur. Monitoring and addressing potential unintended adverse effects ex-ante can be inefficient since circumstances are likely to change over time. Addressing unintended effects when they occur could resolve potential risks, irreversibility, path dependence and lock-in effects.

2.2 Large migrations in infrastructure projects and the role of standardisation

For this subsection, various studies are researched that focus on the technological characteristics which define the ERTMS implementation. These studies are about the complexities surrounding infrastructure innovations and migration. Various infrastructure systems are affected by turbulent technological and institutional change (Weijnen & Bouwmans, 2006). Weijnen & Bouwmans (2006) urge to acquire a better understanding of the dynamic behaviour of infrastructure to steer the process of change towards social benefit. This challenge calls for a collaborative and integrative effort in the form of a knowledge structure which crosses disciplinary borders. In such a structure various challenges in the migration can be dealt with more easily.

This knowledge structure can be formalized into a standard. With a large migration in an infrastructure project, a standard can ensure various parts in this infrastructure system can work together before, during and after the migration. A supplier of parts is given specifications within this standard to ensure proper interoperable parts. However, there are potential negative impacts of standardisation (Tassey, 2000). Tassey (2000) provided various potential negative impacts which must be averted to successfully execute a large migration in an infrastructure project. The first risk is that multiple standards for the same infrastructure technology arise which are incompatible. The second risk is that the standards are poorly designed. The third risk is that the release of these standards are poorly timed. The first two risks are mitigated when performing additional research to better develop infrastructure technologies. The third risk can be mitigated if stakeholders communicate in a collaborative and integrative manner. Besides these risks, standards can limit innovation and lead to establishment of a dominant design paradigm (Maull et al., 2015). Maull et al. (2015) argue that systems should be allowed to evolve and designed for participation with learning, which can be achieved by following not closed but open standards which encourage innovation. This is also confirmed by researchers that examined the similarities between biochemical 'technologies' of nature to innovation-enhancing standards of future technologies (Wagner et al., 2016).

A method to provide insight in an innovation process is roadmapping, which is used by various research organisations (TNO, n.d.; Hasberg et al., 2012). Within migration projects, standardisation roadmapping exercises could prove useful to overcome the challenges of achieving interoperability between different technological systems (Ho & O'Sullivan, 2017). Ho & O'Sullivan (2017) propose a more structured approach to manage these roadmapping exercises which provide insight to stakeholders.

Another solution next to standardisation is the construction of cloud applications (Carpintero et al., 2012). Carpintero et al. (2012) suggest that this provides maximum flexibility in implementation of innovations. Furthermore, older standards can be set aside more easily while focussing more on the innovating freedom. However, this methodology could prove complex when migrating from and to a hardware based system.

2.3 Implementation of technological innovations

Successful technology implementation of innovations is a subject that is important in many different areas. Studies show that technological implementations are an exercise of team learning and urge the importance for the ability to reframe a situation (Edmondson, 2003; Klein & Knight, 2005). Edmondson (2003) describes a frame as a set of assumptions and beliefs about a particular situation. She provides four tactics for reframing. First that a situation or challenge presents an exciting opportunity to try out new approaches and learn from them. Secondly that you are yourself vitally important for a successful process. Thirdly that others are vitally important for a successful process. Finally, that communication between stakeholders should be as if these three statements were true. Reframing can shape behaviour which influences the process in obtaining the desired results. Edmondson (2003) believes that the ability to reframe can lead to achieving better results in an implementation project. Klein & Knight (2005) confirm this in their list of critical key factors that shape the outcome of innovation implementation projects. The first key factor described is the availability of policies and practices that stimulate innovation, like sufficient training and assistance throughout the innovation. The second key factor is an appropriate climate for innovation implementation. In other words, the shared perception of importance for the process. The third factor is the vital importance of the support of managers. The fourth key factor is the availability of financial resources, which can be used for continuous support to stakeholders in the form of campaigning and training. The fifth key factor, as mentioned earlier, is a learning orientation. The sixth and final factor is a long-term orientation of the manager.

This is primary focused on organisational climate and organisational stimulants for successful implementation of innovations. There are various other facets that must be considered. Important elements are technology evaluation, integration, planning, implementation, training and change (Kearns et al., 2005). Kearns et al. (2005) mentioned many different factors each aiding in different goals. This literature review provides the factors and principles that could aid the implementation of ERTMS. To ensure technology evaluation and thus continuous improvement, progress should be measured quantitatively, input from other stakeholders with experience should be gathered and a dedicated team should be enlisted to evaluate the system. Integration is necessary to enable interaction with the implementation process by the stakeholders. To ensure this, operational changes and corresponding reasons must be documented and needs of a specific organization must be deducted. A good planning can provide insight in necessary personnel and resources. To provide the base for such a planning, the scope must be clearly defined to ensure feasible milestones. To maintain integrity and purpose, a strong central leader is necessary to keep project on track. Team members should have technological experience to understand what the project needs. Teams should consists of users and stakeholders from all groups and levels. Finally, project plans should be as specific as possible. The principles of implementation are the testing of new technology, human factors should be considered with changes, customizations or configurations of the system. Contingency plans should be developed in case errors occur in the system with the possibility to run the old and new system parallel until the new system is validated and frequent communication must occur regarding status, obstacles and progress. The principles of change are the following: have corporate support to changing operations, acquire recognition from all stakeholders which can be achieved by communicating goals, progress and reasons for changes, forcing a change by disabling old technology and finally the acknowledgement that change is a continuously ongoing process (Kearns et al., 2005).

Finally, researchers propose an adaptive policy approach to handle uncertainties surrounding the implementation of innovative urban transport solutions (Marchau et al., 2008). Marchau et al. (2008) explored its potential and argue that such an approach is well-suited in handling multiple policy measures. For instance, he researched three cases where an adaptive policy approach would be effective. In these examples, he suggested temporary policy measures until monitored data could provide a more structural base for more long-term policies.

2.4 Complexities on integrated management systems

An integrated management system (IMS) combines various business-related components into one system which enables easier management and operation. These components could relate to Quality, Environmental and Safety management systems (Sci Qual International, 2020). Furthermore, an IMS could be seen as a complex adaptive system (CAS) (Domingues et al., 2015). Domingues et al. (2015)

specify various features which characterize IMSs as CASs which apply to the organizational nature of the Dutch ERTMS implementation. Several effective synergies can be developed when an IMS adopts a CASs approach. To support this idea, Domingues et al. (2015) executed a thorough research of available literature on CAS, especially when closely related to topics related to IMSs.

Domingues et al. (2015) take the continuous improvement constructs ascribed to Deming and Shewart (Moen & Norman, 2009) and introduce it as a suitable tool to assure the learning process in an IMS, which is shown in Figure 3.

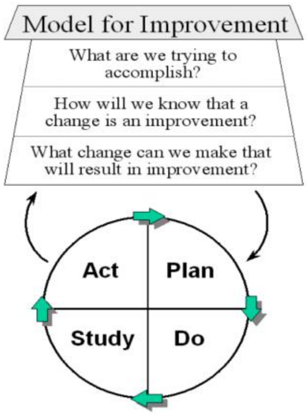

Figure 3: PDSA-cycle, model for improvement, in 2009 (Moen & Norman, 2009).

This model fits within the agile paradigm. The agile paradigm can be defined as follows: agility is the flexibility of an entity to accommodate unexpected or expected changes rapidly (Qumer & Henderson-Sellers, 2008). Use of the agile methodology could potentially save time and money by focussing more on the project than on the required documentation (Shankarmani et al., 2012). However, Sharkarmani et al. (2012) describe three major risks of working with agile methodology. The first is that agile methods are easy to misunderstand. The second risk is that people are quick to think that they are doing agile right, and be wrong. The third risk is that the visibility of values could be embarrassing for the team.

Besides the continuous improvement construct, Domingues et al. (2015) refer to modularity as nature to an IMS. By facilitating loose coupling, these modules could reduce cost and decrease the difficulty of adaptive coordination (Sanchez & Mahoney, 1996). Modularity enables strategic flexibility in not only organizational design, but also product design.

2.5 Adaptability factors

This chapter identifies adaptability factors based on various methods that influence adaptability. Table 3 provides an overview of these methods. In this table, the methods are described using broad questions and the corresponding view on these questions based upon literature. These methods are merged when they occur multiple times throughout this literature review. Furthermore, the methods are merged based on their common ground in the adaptability factors. These adaptability factors are used as base for formulating proposed solutions in chapter 6. All adaptability factors that are identified throughout this thesis are described in section 6.1.

Table 3: Adaptability factors identified in the literature review which are provided in the form of one or multiple methods with questions and corresponding views from literature.

Factor	**Method description**
Stakeholder involvement	**In what way are experts and interest groups involved throughout the process?** Literature: various experts and interest groups must be mobilized. It is important to have frequent routine appointments to update these stakeholders and allow comprehensive feedback. It is beneficial to form formal groups where these activities are carried out (sections 2.1, 2.2 & 2.3).
Process clarity	**Which method is used for providing information to various stakeholders?** Literature: road mapping can be used as method to provide clarity within the project process to the various stakeholders (section 2.2).
	In what way is the status and planning of the project being kept and defined? Literature: the actual status and planning of the project must be clearly defined. This must be measured quantitatively with a clear scope, clear milestones and clear boundaries. All stakeholders must be kept up to date with this planning in a transparent manner. Stakeholders must be able to provide feedback on a frequent manner following the agile methodology (sections 2.3 & 2.4).
Operational compatibility	**How are effects of operational choices being tested?** Literature: an extensive simulation must be executed to test operational and technological choices to provide clarity in the effects that such choices could have (section 2.3).
Leadership	**How was leadership being organized throughout the project?** Literature: a strong central leader must be defined to ensure integrity and purpose. This leader must be acknowledged by all stakeholders. In turn, this leader must acknowledge the various interests of the different parties and must be able to steer the process into a direction that further aligns with goals of all parties (section 2.3).
Flexibility management	**In what way are the policies being defined throughout the process?** Literature: policies must be defined when certainties within the project arise. A legislation environment should be set up in where policies can adapt to various scenario's instead of defining static policies in a single point in time based upon insufficient information. Dynamic policies can address unintended effects when they occur (section 2.1 & 2.3).
	In what way is flexibility being maintained during the process? Literature: technological and organizational flexibility should be maintained to preserve the ability to reframe goals and targets throughout the project as response to unforeseen developments (sections 2.1, 2.3 & 2.4).
	In what way is uncertainty being handled throughout the process? Literature: uncertainty must be addressed as exercise of team learning. Unknown parts are a certainty in large innovation projects. However, the organizational process must be arranged in such a way that flexibility and alignment between stakeholders allow to adapt to uncertainty (sections 2.1, 2.3 & 2.4).
Modularity	**Is the process built in a modular fashion?** Literature: the technological and organizational structure is built in a modular fashion such that components that become outdated can be replaced without the necessity to replace multiple parts resulting in capital destruction (sections 2.2 & 2.4).
Standardisation	**Are standards used throughout the process?** Literature: by using standards for technological parts, interoperability can be ensured. A single standard must be dominant and must not leave room for interpretation which could result in poor practices. Furthermore, new standards must be used following the interests of the various stakeholders (section 2.2).

3. ERTMS basics

This chapter provides an analysis on various aspects of ERTMS. Section 3.1 starts with a short definition. Section 3.2 provides a brief history. Section 3.3 provides further explanation on corresponding baselines, releases and versions. Section 3.4 lists the components that form the planned Dutch ERTMS implementation. Section 3.5 provides a stakeholder analysis. Section 3.6 will gives a brief evaluation on the migration processes of other European countries and the lessons learned. Finally, section 3.7 will conclude by providing critical issues that are important for strengthening the adaptability of the Dutch implementation of ERTMS towards the future.

3.1 Definition

ERTMS (European Rail Traffic Management System) establishes a standard for the railways throughout Europe in such a way that these are interoperable. In this standard a train with ERTMS on-board equipment can run on corridors equipped with ERTMS trackside equipment. Both should be interoperable independently of its supplier. ERTMS mainly consists of two subsystems. The first is ETCS (European Train Control System), which is a train control standard. ETCS is able to supervise movement and can stop the train if the speed exceeds a maximum speed based on a corresponding calculated braking curve or a specified ceiling speed. This process can be performed with the ETCS equipment on the train and equipment on the track. The second subsystem is GSM-R (Global System for Mobile Communications – Railways). This refers to the radio communications standard used for railway operation (EC, 2020). Officially, ERTMS also contains ETML (European Traffic Management Layer) and EOR (European Operating Rules) (Jarašūnienė, 2005). The first is not established yet and the latter is available, but not obligated (ERA, 2019).

3.2 History

The standardised ERTMS system is meant as an interoperable replacement for the current block signalling and ATP systems that vary throughout Europe. Every country has its own systems which are normally not compatible with the systems of other countries. Without this compatibility, international trains require several corresponding on-board units that enable crossing into different signalling areas. Due to the growth in international rail services, a standardised block signalling and ATP system was needed in Europe. This was also the conclusion for the European Economic Community (EEC), that launched a study in 1989 (UNIFE, 2020). After this study, the ERTMS Users Group (EUG) was founded to design an initial version of the functional specifications. This group originally consisted of only technological experts from infrastructure managers.

The first specifications were created in April 1999 with the help of UNISIG, an industrial consortium created by main European signalling companies to help developing the ERTMS specifications. The European Commission signed for these first specifications in 2000 and thus the process of increasing interoperability of railway control, command and signalling started (Arenas, 2015; Jarašūnienė, 2005; EC, 2020). Interoperability ensures safe international train travel. A the train must be able to pass through a border without the necessity to stop which contains the aspects that no required change of locomotive and no required change of driver is needed. Furthermore, it contains the aspect of using only standardised tasks compliant with ERTMS.

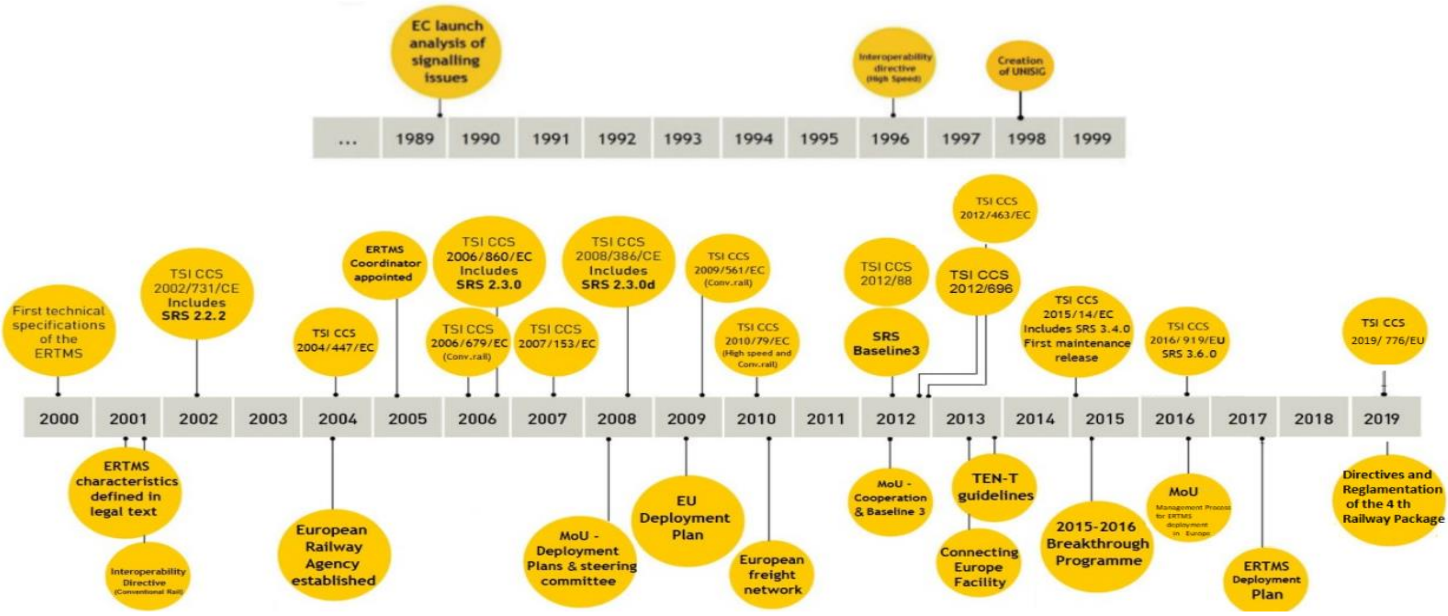

Figure 4: The History of ERTMS (Ruete, 2020)

In 2004, the European Railway Agency (ERA) is established to function as ERTMS system authority and is designated to manage the system specifications (EC, 2020). The sector produced, in 2005, its first, Memorandum of Understanding (MoU) focused on the implementation strategy. These MoU address the main challenges during that specific stage. For example, the last MoU in 2016 established a framework which provided technical and legal certainty for operation of trains on compatible lines and thus formalised the integrated management process for ERTMS deployment throughout Europe (EC, 2020). An overview of the various events are visualized in Figure 4.

3.3 Baselines, releases and versions

ERTMS is a rail safety standard which is documented in a set of specifications, which stand for Technical Specifications for Interoperability (TSI). The ERA updates these specifications in the form of baselines and/or releases. The ERA currently provides three official sets of specifications (ERA, 2019). The first set is baseline 2 (B2). The second set is baseline 3 maintenance release 1 (B3MR1) and the third set is baseline 3 release 2 (B3R2) (Zigterman, 2016; ERA, 2019). In 2022, the next set of specifications is planned to be issued (Ruete, 2020; EIM, 2019). It is still unclear if this is another release of baseline 3 or that it will be defined as baseline 4. These sets are visualized in Table 4.

A set of specifications contains documents specifying aspects, components, interfaces, etc., concerning the architecture of ERTMS (EC, 2020; ERA, 2016). Each current set consists of an ETCS baseline and a GSM-R baseline. All current issued sets have GSM-R baseline 1. The ERTMS standard specifies the boundaries to which suppliers of the technical systems are required to comply. However, there are differences between the boundaries set in different sets of the ERTMS standard. Thus, TSIs are not fully compatible with each other. The European Commission sets mandatory ERTMS baseline requirements for new rail systems (EC, 2016). Thereby following technical developments in this field and providing guidance in the insurance of interoperability (Siemens, 2018; Zimmermann & Hommel, 2003). Currently, the Netherlands is planning to implement ERTMS based on B3R2 (or System Requirements Specification (SRS) 3.6.0) (BCG, 2018). SRS is an alternative definition for a set of specifications. The current Dutch ERTMS implementations are all based on B2, which could require an upgrade (Min I&W, 2019). Newer sets have various changes inserted which improve the entire system or add new functionalities. A change is called a change request (CR) and can be defined as error correction or enhancement. For instance, between B2 and B3MR1, there have been 436 CRs (UNISIG, 2014).

Table 4: Overview of various sets of specifications

Set	Baseline	SRS	System Version (SV)	Released
Set 1	Baseline 2 *(B2)*	2.3.0d	1.0	2008
Set 2	Baseline 3 Maintenance Release 1 *(B3MR1)*	3.4.0	1.0, 1.1, 2.0	2015
Set 3	Baseline 3 Release 2 *(B3R2)*	3.6.0	1.0, 1.1, 2.0, 2.1	2016
Set 4	*Baseline X Release X*			*Expected in 2022*

To ensure interoperability, the European Commission devised a system in which the baselines are constructed. Thus, the ability to introduce backwards compatibility between the baselines (EC, 2020). However, general compatibility between baselines cannot be ensured, only higher or equal versions of the on-board unit (OBU) on lower or equal versions of the trackside. This is stated in section 4.4.1.2 in the engineering guideline about international interoperability (EUG, 2017). This is visualized in Figure 5.

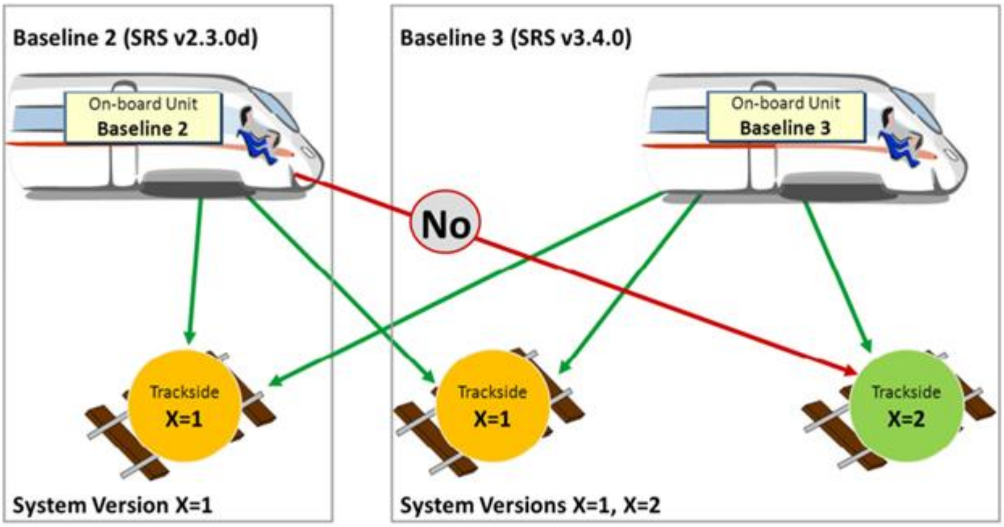

Figure 5: Compatibility between on-board compliant with a specific baseline and tracksides operating with specific system version (UNISIG, 2014).

However, the compatibility is more elaborated than that. A set of specifications can be described as box of various tools. Within s specific set, system versions (SV) are specified. In other words, the SV is not attached to a specific set of specifications. The European Commission defines a SV as ETCS mandatory functions that ensure technical interoperability between ETCS on-board equipment and trackside (ERA, 2016). In other words, the SV refers to the version of the ETCS language in the exchanged data between both train and trackside subsystems. It identifies the available functionalities that can be used. A SV is specified as two numbers (X.Y) as seen in Table 4. The X distinguishes non-compatible versions. It is the version ordered by trackside equipment. Y indicate compatibility within a version X and defines the version number of the system (Table 4) (ERA, 2015). On-board equipment constructed according to a specific baseline can handle all SVs within that specific baseline and older.

However, the infrastructure is constructed with a specific SV and baseline. Thus creating the incompatibility between tracksides of a higher X within the SV and on-board equipment of a lower X in the SV, as visualized in Figure 5 and Figure 6. In the first figure there is a trackside SV X=1, constructed following the baseline 3 specifications which can support both the trains in the example. However, while this can support more features than the trackside SV X=1 constructed according to B2, it supports less features than the trackside SV X=2 within baseline 3. In short, if both trainside and trackside operate on X=2 instead of X=1 they can provide more functionalities. Furthermore, Y=2 provides more functionalities than Y=1.

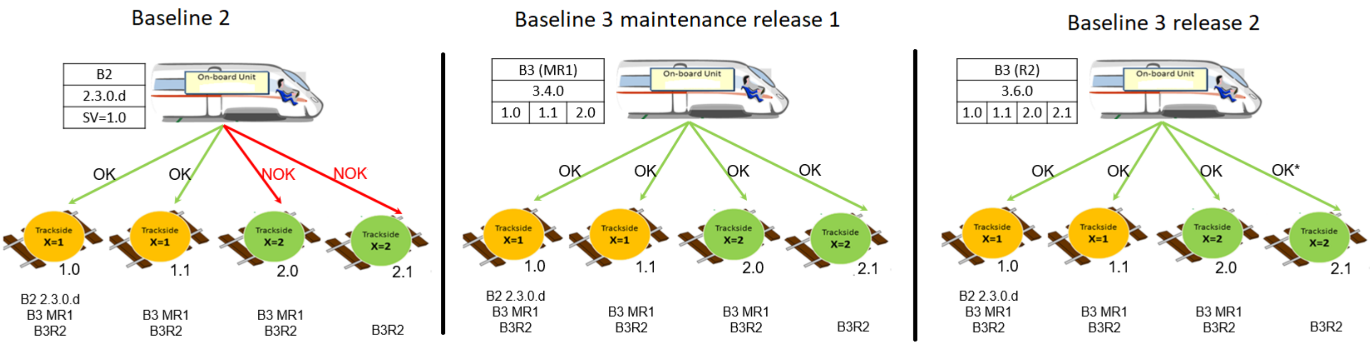

Figure 6: compatibility between SVs of on-board and trackside equipment. Edited image from Arenas (2015).

Currently, the second release of B3 (SRS 3.6.0) is used as specification for the planned implemention of ERTMS within the Nederlands, as described earlier. According to a baseline compatibility assessment executed by the ERA, UNISIG and the ERTMS Users Group, both releases of B3 are compatible with each other, as shown in Figure 6 (SRS 3.4.0 and 3.6.0) (ERA, 2016).

3.4 Components

Within the structure of the TSI, components of ERTMS are specified. The components can be divided into two subsystems. The on-board subsystem and the trackside subsystem. This subsection describes the ERTMS components and the components that are interfaced and part of the planned Dutch ERTMS implementation. This section provides a figure that provides the different components and their position in the system (Figure 7). These components and their functionality are further explained in the comprehensive conceptual model in chapter 4.

The technical specifications used in this thesis are from the most recent TSI, which is used for the Dutch implementation (B3R2 / SRS 3.6.0). These are described within subset 026-2 (system requirements specification chapter 2: basis system description) provided by the ERA (ERA, 2016). The various components are specified in Figure 7. The components are visualized conform the various sources besides this subset. The first is the ERTMS traffic system architecture provided by the Dutch ERTMS program (Programma ERTMS, 2018). The second is the technical reference for the architecture used by ProRail (ProRail, 2018). Furthermore, various definitions are gathered using glossaries from the ERA and ProRail (ProRail, 2005; ERA, 2019). Besides the literature, the model is been discussed with various experts, such as ProRail experts on ERTMS, ICT and TMS and a EULYNX data architect. The interviews with these experts are summarised in appendices F.1 to F.3 & F.5. More information of the used sources can be found in section 4.1.2.

In Figure 7, a distinction is made between standardised ERTMS components and non-standard components. This figure indicates an area, marked with the red dotted line, in which the components are within the scope of the ERTMS standard. The components that are located outside this area are not specified in the TSI and are non-standard. Furthermore, Figure 7 provides classification between personnel, non-vital control components and vital safety components. Each component that is responsible for ensuring that safety measures are respected falls within the latter classification.

This distinction provides means to identify easy adaptable components and components that are more difficult to change. Non-standard, non-vital components are very adaptable. While ERTMS components that are vital for safety are the least adaptable due to required safety cases and analyses that would be needed if this components requires a change.

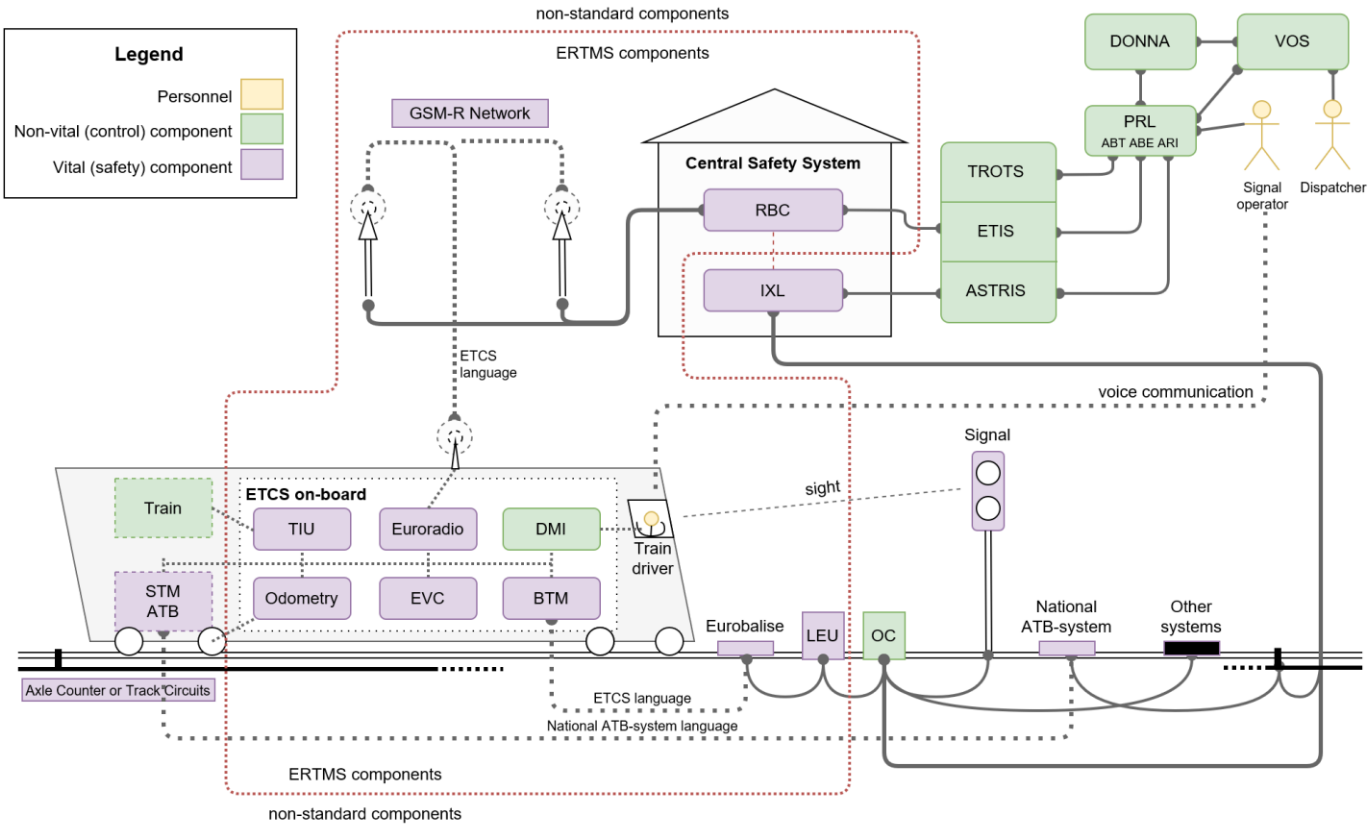

Figure 7: Sketch of used components in the planned Dutch ERTMS implementation

3.4.1 On-board subsystem

From Figure 7, various components are shown that are situated in a train each with an own function. These functions are described in Table 5. Within the planned Dutch ERTMS implementation three main parts can be deducted. The first cluster of components belong to the ETCS on-board equipment. These components purely enable functions required for the safety system corresponding to the ERTMS specifications. The second is the interface to the existing national safety system using a STM and the third are the actual train command and control components.

Table 5: Name and description of components within the on-board subsystem.

Name	Description
ETCS on-board	European Train Control System on-board equipment is used for control and commands parts of ERTMS. Described in section 3.1.
TIU	Train Interface Unit. This vital unit provides the interface between the ETCS on-board equipment and the train variables. For example, motion controlling variables such as speed, braking and acceleration.
Euroradio	The various vital functions and protocols which are required to provide safe communication between on-board and trackside equipment. For example between the RBC and the EVC.
DMI / Train driver	Driver Machine Interface. This non-vital interface enables communication between on-board equipment and the train driver.
BTM	Balise Transmission Module. This vital module enables intermittent transmission between the track and the train, which can process and retrieve data from a trackside Eurobalise.
EVC	European Vital Computer. The vital core of the ETCS on-board device which provides the logic for train protection and supervision. It interacts with all other ETCS train components.
Odometry	Vital equipment which is used to measure movement of a train. This can be used for speed and distance determination.
STM ATB	Specific Transmission Module Automatische Treinbeïnvloeding (Automatic Train Protection). A vital and non-standard module which can be interfaced to an existing National Train Control system, thus allowing smooth transitions between the National system and ETCS. ATB is the Dutch existing national ATP system.
Train	Command and control part of the train itself. This consist of various vital systems like the TIM (Train Integrity Monitoring) system for it is included in the Dutch ERTMS program (Programma ERTMS, 2019). Furthermore, a non-vital system is the braking and traction system.

3.4.2 Trackside subsystem

In Figure 7, various components are shown that are situated outside the train. These trackside components each have their own function. These functions are described in Table 6. These can be categorized in three parts. The first part consists of the decentralized, lineside components. Components like the Eurobalise, the LEU, the signal, the national ATP-system, the object controller, the axle counters or track circuits and other systems. The second part consists of the Central Safety System (CSS) which is an IXL and RBC combi-system. The third part contains the planning, management and control software systems that adjust and optimizes network flow. These systems are DONNA, VOS, PRL and their interface software systems: TROTS, ETIS and ASTRIS.

Table 6: Name and description of trackside subsystems.

Name	Description
Axle counter	A track-clear detection device that counts passing axles. This vital non-standard device can be used for train detection and integrity.
Track circuits	A track-clear detection device using track circuits originally developed by the General Railway Signalling Company. It uses electrical AC voltage to detect if a block is occupied or not. This vital non-standard device can be used for train detection and integrity.
National ATB-system	National Automatische Treinbeïnvloeding (Automatic Train Protection) System. In the Netherlands there are various legacy components such as the ATB-circuits. These vital non-standard coded track circuits are integrated in the GRS track circuits.
Eurobalise	A passive vital beacon which is used to transmit fixed or variable data to passing trains. An Eurobalise is a balise which is compliant to the ERTMS specification. For example, it can transmit a specific location to a passing train.
LEU	Lineside Electronic Unit. A vital device used in ETCS L1 for communication between signalling components and the switchable (variable) Eurobalises.
Signal	Line side fixed signal posts intended to display various aspects instructing the train driver about required train movements. This is a vital non-standard component.
Other systems	There are several components that depend on ERTMS. Examples are switches or level crossing protection. These are vital and non-vital non-standard components. Further information on these systems can be found in the conceptual model in section 4.1.2.
OC	Object Controller. A non-vital component which is used to control objects.
GSM-R network	Global System for Mobile Communication – Railways. This vital system provides a method for ERTMS to transmit data between track and train.
Central Safety System	The integration of the IXL and RBC that is specified in the Dutch ERTMS program (Programma ERTMS, 2019).
RBC	Radio Block Centre. A vital standardised central unit which receives data on train positions and interacts with the IXL to formulate messages, such as MA's, to trains.
IXL	Interlocking. A vital non-standard cluster of systems each intended to control the setting and release of routes and points to prevent unsafe conditions.
ASTRIS	Aansturing en STatusmelding van de RailInfraStructuur (control and status reporting of the infrastructure). A non-vital software interface developed by ProRail between the TMS and the interlocking. Part of the Traffic Control System (TCS).
ETIS	Electronic train information system. Non-vital software used for delivering real-time train data concerning passenger and freight trains between the RBC and the TMS. Part of the TCS.
TROTS	TRein Observatie & Tracking Systeem (Train Observation and tracking system). This non-vital software generates a train identification number attached to a certain section occupation and follows this number on the rail network as discussed with the ProRail ICT expert. The interview can be found in appendix F.2.
PRL / Signal operator	Procesleiding (Process Management). Non-vital software that functions as TMS which, based upon a predetermined plan, sets routes for trains and uses the following interfaces to communicate to ASTRIS, ETIS and TROTS. Signal operators use this software to acquire knowledge on the infrastructure and traffic state in order to set routes.
ABT	Automatische Beinvloeding TROTS (Automatic control TROTS). A non-vital software interface between PRL and TROTS which automatically provides instructions.
ABE	Automatische Beinvloeding ETIS (Automatic control ETIS). A non-vital software interface under development between PRL and ETIS which automatically provides instructions.
ARI	Automatische Rijweginstelling (Automatic Route Setting). A non-vital software interface between PRL and ASTRIS which automatically provides instructions.
VOS / Dispatcher	Verkeersleiding Ondersteunend Systeem (Traffic Management Support System). Non-vital planning software which is used for last-minute planning. The dispatcher uses this system to make interventions in operations.
DONNA	Non-vital planning software which is used for constructing timetables.

3.4.3 Modes

ETCS equipment can exchange information in a specific manner. This is dependent on the application level (section 3.4.4) but also on the chosen mode. In the TSI B3R2, 17 different modes are mentioned (ERA, 2016). This section will describe the notable modes based on the definition given in chapter 4 of SUBSET-026:

- **Full Supervision (FS):** This mode is automatically entered when all required train and track data is available on-board. The EVC supervises train movement against a dynamic speed profile.
- **Limited Supervision (LS):** This mode enables operation of a train in areas that supply trackside information to realise background supervision. For instance, when ETCS does not receive information about the state of the lineside signals because they may not exist. A more detailed description of ETCS with LS can be found in appendix C.
- **Staff Responsible (SR):** This mode allows the train driver to execute train movements under own responsibility. This mode can be activated if, for instance, the train equipment starts-up.
- **On Sight (OS):** This mode enables the train to enter an occupied section. It must be commanded through trackside components. This mode is used for coupling.
- **Shunting (SH):** This mode enables shunting movements. On-board equipment executes the train position function. The RBC is not required. The driver takes responsibility due to partial supervision.
- **National System (SN):** This mode allows the national system to access ETCS components like the DMI, odometer and TIU. This disables supervision provided by the ETCS on-board equipment.

3.4.4 Application levels

ETCS application levels define possible operating relationships between track and train, each enabling different functionalities (ERA, 2016; Thales, 2017). These refer to the used trackside equipment, methodology of communication between track and train and which functions the ETCS on-board equipment processes (ERA, 2016). All levels make use of cab-signalling with continuous speed supervision and braking curve supervision. It is possible to mix levels on the same track. ETCS is configurable in various levels but three levels are customary in practical use (ERA, 2016). These three levels and some other relevant configurations are described extensively in appendix C. With each increasing level, more functionalities are performed by on-board equipment instead of trackside equipment. Examples of these functionalities are signalling and train integrity. Besides that baselines are downward compatible (section 3.3), levels are also downward compatible in a similar manner. For example: on-board equipment operating on ETCS L2 can operate on trackside ETCS L1 and L2.

Currently, the Netherlands is deploying ETCS L2 (Min I&W, 2019). This level is a radio based train control system which utilizes the RBC to provide movement authorities and track descriptions. This level still requires some lineside equipment. The Eurobalises are mainly used for location referencing and train detection and integrity is performed by axle counters or track circuits. While the current deployment utilizes ETCS L2, the trackside and trainside in the Dutch ERTMS program is prepared for the utility of ETCS hybrid level 3 as argued by the interviewed ERTMS expert: “Hybrid Level 3 can be utilized according to the current planned Dutch ERTMS implementation” (appendix F.1). This is confirmed by the stakeholder manager of NS (appendix F.19). Hybrid level 3 (HL3) is a hybrid between level 2 and 3, allowing trains with and without on-board integrity equipment. This on-board component is called a TIM system (Train Integrity Monitoring). According to the ERTMS Users Group, this application level is still under development (EUG, 2018). Hybrid Level 3 is described as innovation in section 4.2.1.

3.4.5 Characteristics of functionality

As described ERTMS consists of various parts that are utilized according to a certain manner providing various functions. By using the GSM-R network, data transmission can be continuous between track and train. This enables the ability to use continuous speed and braking curve supervision by the EVC. This is communicated by the DMI to the train driver, thus giving continuous information about the system state, such as current speed information, braking curves and MA's. This functionality is called cab signalling. This enables a continuous checking of driver ability and attentiveness while independently performing ATP supervision if train exceeds the maximum allowed speed based on a calculated braking curve or a specified speed ceiling.

3.5 Stakeholder analysis

This section provides an analysis on the governance and stakeholders that have interest in the Dutch implementation of ERTMS. It starts with an overview of the used governance and decision-making model. Thereafter, a description of the involved stakeholders is provided.

3.5.1 Governance and organization

The model used for governance, which is shown in Figure 8, is based on a governance model for large projects issued by the Dutch government for such projects (Rijkswaterstaat, 2001). However, due to expertise of ProRail in the rail sector the program director and management has been placed within ProRail instead of the Ministry (Figure 8) (Programma ERTMS, 2019; ProRail & NS & Min I&W, 2016).

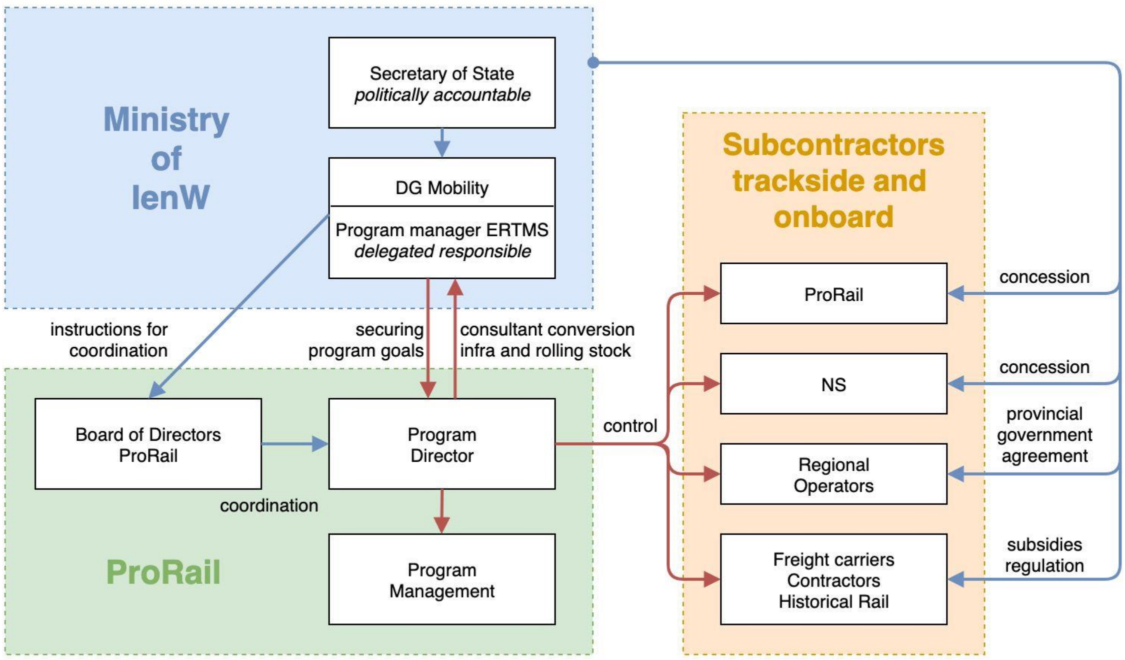

Figure 8: Dutch governance model for the ERTMS implementation. This is a translated model in the ERTMS implementation plan (Programma ERTMS, 2019).

Besides this governance model. A model has been used to set-up the decision-making process during the ERTMS implementation. This is shown in Figure 9. In this figure, the ERTMS management, the program director and the program manager ERTMS is shown, identical to the previous figure. However, the steering group is added. This group consists of high interest stakeholders. Examples are, directors from DG Mobility, ProRail, NS, regional and freight operators, leasing companies and infrastructure contractors. Beside the main structure of the model. An ECF (Eigenstandige controle functie)(independent control officer) and CIO (chief information officer) are added to provide various forms of independent advice. Furthermore, to support the accountability and decision-making function of the steering group. PBO (Programma Beheersingsoverleg)(Program Manage Meeting) and DO's (Directeuren overleg)(Directors Meeting) are used to exchange information and determine positions and opinions.

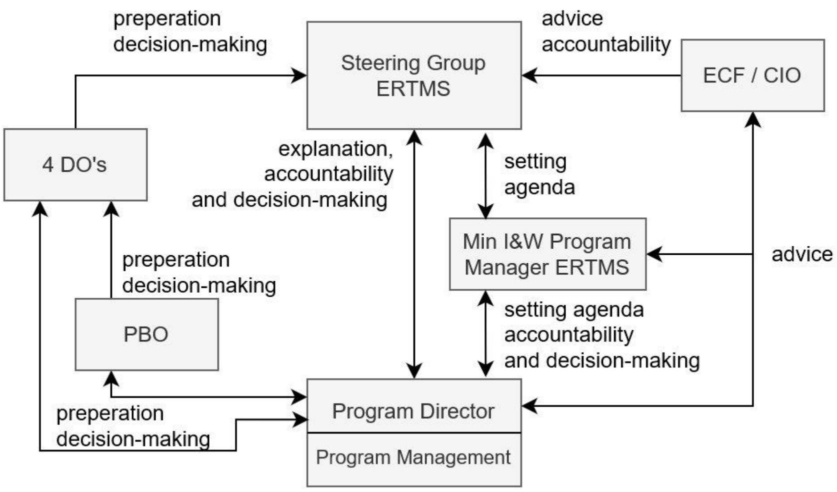

Figure 9: The model used for the decision-making process. This figure is a translation of the model prescribed in the ERTMS implementation plan (Programma ERTMS, 2019).

3.5.2 Stakeholders and their interests

According to the stakeholder alignment process within the main ERTMS program dossier, the primary stakeholder groups can be categorized into eight categories. These categories are: the program partners, the train owners and operators, decentralized authorities, port authorities, traveller organisations, infrastructure managers, market parties, users and international stakeholders (Programma ERTMS, 2019). A summary of the various interests can be found in Table 7. These interests are based on the program decision provided by the ERTMS program. The extended description of the stakeholders can be found in appendix D.

Table 7: Stakeholder overview with provided examples and their summarized interests

Stakeholder	Interests
Program Partners *(Min I&W, ProRail and NS)*	The responsibility of the migration lies with the program partners. This consists of the submission of interests, connecting the operational and technical processes between the ERTMS program and the interests of the program partners. • The Ministry desires a cost-efficient migration with minimal hindrance for travellers and shippers (Min I&W, 2019). • ProRail, as infrastructure manager, would like to minimize trackside equipment while maintaining safe operations, thus decreasing costs. • NS would like to maintain a controlled migration towards ERTMS, thus wanting the retrofitting and upgrading of their equipment before the roll-out on the infrastructure (Wever, 2016).
Train owners and operators *(e.g. Arriva, DB Cargo, Beaconrail)*	These stakeholders have a very high interest with the roll-out of ERTMS. They desire a controlled migration from the legacy system to the new system with a minimization of financial and operational hindrance.
Decentralized authorities *(e.g. Province of Groningen)*	In accordance with regional environmental visions and goals, decentralized authorities want to acquire the benefits of ERTMS in their own region. The migration should not decrease the accessibility and punctuality in their region.
Port Authorities *(e.g. Port of Rotterdam)*	As these stakeholders want to maximize freight throughput, the improved rail interoperability between neighbouring European countries is seen as beneficial. However, the migration should not decrease rail accessibility.
Traveller organisations *(e.g. Rover and Locov)*	Traveller organizations are positive about the migration towards ERTMS and see it as opportunity to improve on accessibility throughout the Netherlands. They would like to maximize the benefits for the traveller.
Infrastructure managers *(e.g. Strukton Rail Short Line)*	Various tracks are managed by different parties than ProRail. These IMs would like to preserve a good connection to the main network without problematic operational transitions for their (shunting) locomotives.
Market Parties *(e.g. Siemens and Movares)*	ERTMS suppliers, engineering and constructing companies should make their expertise and abilities clear such that a realistic program can be formed and these experts can be utilized in an optimal manner. Which is beneficial for all parties.
Users *(e.g. Train drivers, signallers and dispatchers)*	The changing of operational processes should take the end-users into account. These processes should be unambiguous throughout the rail network with good corresponding education.
International stakeholders *(e.g. EU Governments and IMs)*	Interoperability towards neighbouring countries are an important goal of the ERTMS implementation. Alignment between constructing parties and programs is of importance.

3.5.3 Conclusion

From this stakeholder analysis can be deducted that the Dutch ERTMS implementation affects various different stakeholders. However, there are three stakeholders that are mainly involved: Min I&W, ProRail and NS. However, in the current situation, the ERTMS program is positioned at ProRail. This could decrease the balance in served interests between different stakeholders as described in the identified adaptability factor on leadership mentioned in the literature review (section 2.5).

3.6 European implementation processes

To acquire more knowledge about potential risks in the implementation of ERTMS, a research is conducted on other implementation processes within Europe, the lessons learned and European initiatives to improve the efficiency and effectiveness of the ERTMS implementation. The implementation processes are not without challenges (Smith et al., 2012). Smith et al. (2012) carried out a research that went in-depth about learned lessons in the creation and implementation processes of ERTMS. They did specify three factors that emerged in their research to be necessary for the successful deployment of ERTMS. The first factor prescribes that there is a need for a cohesive working relationship between the infrastructure manager (IM) and railway undertaking (RU). The second factor is that colleagues from different stakeholder companies should interact more on informal basis. The third factor prescribes an increased focus on operational rules in addition to technology. These factors are confirmed by Li et al. (2018) who researched enhanced cooperation among stakeholders in a public-private partnerships in mega infrastructure projects (Li et al., 2018).

3.6.1 Current state

This section provides insight in how European member states implement ERTMS and the corresponding issues that could arise. These processes are described to serve as example for the Dutch ERTMS implementation.

Switzerland has various lines with ETCS L2 which are all based on B2 and has various lines with ETCS L1 Limited Supervision (LS) which are based on B3MR1. Thus, vehicles that have ETCS only must have B3MR1 or a newer TSI. Switzerland implemented the first B3 RBC of Siemens without many operational problems. A general roll out of ETCS L2 is planned from 2025 upward due to replacement of old relay interlocking systems (Hänni & Zurflüh, 2017). Furthermore, this roll out of ETCS L2 is also linked to a replacement of GSM-R. The implementation process is even stopped for five years to better prepare for the replacement of GSM-R. The interviewed independent rail advisor stated:

> "Switzerland has high focus on familiarizing with new technologies and is prepared to stop the implementation process for it. One of the reasons this can be done, is because the national government has a high focus on these innovations." (appendix F.4).

For Germany, the migration towards B3MR1 is mostly started due to European regulation. The current ATP systems PZB 90 and LZB are very similar to respectively ECTS L1 LS and ETCS L2 (Eisenbahn-Bundesamt, 2017). However, support by the industry for LZB is ending after 2030 (McKinsey & Company, 2018). The infrastructure manager of Germany, DB-Netz, plans for an ERTMS-only system that replaces their entire legacy system. However, until 2025 both signalling systems will be operational (DB Netz AG, 2019). As of October 2017, 235km is equipped with ERTMS B2 L2 and around 16,5km equipped with ERTMS B3MR1 L1 LS. By 2023, 1817,8km should be equipped with B3MR1 operating with ETCS L1 LS or ETCS L2 (Eisenbahn-Bundesamt, 2017). According to the German vision, the migration is completed before 2040. The current focus in the process is on the needs of the freight transport sector for a cross-border rail system (Eisenbahn-Bundesamt, 2017).

Belgium is planning to implement three combinations of different baselines and levels throughout its conventional network over the legacy system before 31 December 2022 trackside and 31 December 2023 trainside (ERTMS B3R2 L1 LS, ERTMS B2 L1, ERTMS B3MR1 L2). Which means that the former ATP systems will continue in operation. These legacy systems will be gradually removed until, in 2035, all infrastructure will be ETCS only (Infrabel, 2016). All vehicles will be ETCS only from 2025. The upgrade towards a complete B3 ETCS L2 trackside system is planned from 2025 (Federal Public Service for Mobility and Transport, 2017). The Belgian implementation of ETCS L2 experienced delay due to problems in the selection process. The infrastructure manager, Infrabel, began the tender for the contract in 2011. This process ended with the selection of a consortium THV Siemens – Cofely Fabricom. However, the other potential candidate, the consortium Alstom – VandenBergh – Engema – Stevens, contested this decision resulting in delay. Later in 2015 the contract was officially signed for the rollout of ETCS L2 (Barrow, 2015; DeTijd, 2015).

The United Kingdom started preparation in 2005 with the ERTMS implementation of the Cambrian Coast Line. It was put into service in 2011 with ETCS L2. The following lines that were migrated towards ERTMS that also utilizes ETCS L2 (UNIFE, 2014). This is only an initial step because the goal is to migrate to ETCS level 3 as soon as technology readiness allows (Department for Transport, 2018). The goal to achieve a merge of a Connected Driver Advisory System (C-DAS) and Automatic Train Operation (ATO) as described explicitly in their implementation plans (Department for Transport, 2018). According to Smith et al. (2012) the implementation experienced several key challenges. Such as malfunctioning DMI, BTM failure, confusion in the RBC, differences between miles and kilometres per hour and odometer faults.

Denmark, as torchbearer for the ERTMS implementation in Europe, concluded that its national ATP system was obsolete. Thus it started the implementation early. This was done using baseline 3 release 1 (SRS 3.3.0) on Fjernbane Vest, half of Denmark's infrastructure, and in the on-board equipment (Holst Møller, 2018; Banedanmark, 2018). However, this version was withdrawn by the ERA due to errors in the specification. Later, a maintenance version was released to mend these errors (B3MR1) (EC, 2012, 2015). While its operational performance on the first ERTMS corridor functions properly, the on-board equipment based on SRS 3.3.0 cannot function abroad and is likely to be unable to operate from 2030 on the central station of Copenhagen (Banedanmark, 2018)(appendix F.4). Denmark has decided to roll out ERTMS B3MR1 with ETCS L2 on their state network before the end of 2030 (Transport-, Bygnings-og Boligministeriet, 2019). Besides the infrastructure, the on-board equipment was also based on the withdrawn version as mentioned. This also caused delay because the design phase was longer than anticipated. There were issues with train documentation and software management (Bowers, 2017). Engineers from Denmark's infrastructure manager, Banedanmark, argue that Alstom, as on-board contractor did not perform as hoped as they should deliver a product according to the revised SRS 3.4.0 product certification. Alstom says that the hinder was due to the complexity of the project and that the delivered on-board equipment with SRS 3.3.0 was according to the agreed contract (Väylä, 2019; Banedanmark, 2018). All in all, the problems resulted in an announced 7 year delay (Smith, 2018). Opaqueness in the ERTMS implementation resulted in problems for the freight rail sector. This sector argued that unclear instructions on the chosen SRS, on the deployment of the STM and the chosen road to the harmonisation with neighbouring country Sweden led to unnecessary high costs (Barrow, 2016).

Finally, Luxembourg is the first country that completely implemented ERTMS on their national railway network. Their network is relatively very small compared to other European countries with only 275 km of tracks (EC, 2020). From 2017, the network was based on baseline 2 (SRS 2.3.0d) with ETCS L1 (Friden, 2018).

3.6.2 Lessons learned

According to a paper by Ruesen & Tamarit (2018) from the ERTMS Users Group, there are various lessons that can be learned from the first pilot projects. The first is that, when a specific release of the TSI must be chosen, this choice must be solid and transparently made towards stakeholders. When the original baseline 2 was introduced, various updates followed this introduction until settling at SRS 2.3.0d, which is the current first official set of specifications. These various versions brought about various problems in interoperability (Ruesen & Tamarit, 2018). Besides this technical interoperability, Ruesen & Tamarit (2018) argue that operational interoperability, that correspond with human factors, is 50% of total interoperability.

Furthermore, EC auditors concluded in 2017 that the deployment of ERTMS was of low quality and represented patchwork (Barrow, 2017). One of the issues reported was the low availability of budget. Besides the infrastructure managers and operators, who have been reluctant to invest, the EC itself did not began to study the actual cost until 2015. Besides the low availability of budget, the funding was not invested in accordance with the specified goals of the EC. A second issue argued by the auditors was the lack of coordination in the provided numerous documents which described obligations, priorities and deadlines. A third issue was the lack of cooperation between rail stakeholders and ERTMS suppliers to ensure stability within the implementation process. These three issues can explain that the ERTMS implementation is lagging far behind the original plan, with just 4,121km equipped instead of the planned 10,000 to 25,000km (Barrow, 2017).

3.6.3 European initiatives

To improve adaptability of the ERTMS implementation, various initiatives are setup by partner collaborations between different IMs and RUs. This subsection will describe the following programs and initiatives: Shift2Rail, EULYNX, RCA and OCORA. The Shift2Rail Joint Undertaking is established by the European Commission to contribute to addressing the challenges faced by the rail sector with research and innovation (Shift2Rail, 2015). This is done by organizing demonstration activities, developmental activities and support of projects that are stated in their multi-annual action plan (Shift2Rail, 2019). One of these projects is LinX4Rail that tries to establish an automated and standardised conceptual data model for the railway system architecture (EC, 2020).

EULYNX, as European initiative by thirteen IMs, tries to standardize trackside interfaces (EULYNX, 2019). Furthermore, EULYNX works on a Data Prep standard for the data between IMs to signalling suppliers to decrease the chance for errors by prescribing the semantics of the data (Janssen, 2019). The interviewed EULYNX Data Architect about the Data Prep format: "… in the form of information through an ontology or data in the form of XML code." (appendix F.5). The EUG and EULYNX launched in 2018 the RCA (reference CCS architecture) group. CCS stands for Control Command and Signalling. This group is meant to create a harmonized architecture of the future trackside CCS (EUG & EULYNX, 2018, 2020). For this reason, the RCA group is involved in the LinX4Rail project mentioned earlier. While EULYNX focusses mainly on trackside equipment. OCORA (Open CCS On-board Reference Architecture) is focussed on on-board equipment. It is meant as platform for cooperation between RUs to develop an open architecture that is consistent and established in a modular manner (OCORA, 2020). Modularity can be achieved through standardisation of the interface and facade patterns between objects. A similar project is open ETCS initiated by the Deutsche Bahn (ITEA3, 2016; Hase, 2014). However, the open architecture raised questions about responsibilities surrounding safety.

3.6.4 Facade pattern

In this thesis, the definition of a facade pattern is provided by the interviewed data architect from EULYNX. He states: “The facade pattern is an Object-Oriented design pattern whereby systems are loosely coupled such that either system is little affected by changes “beyond the facade”.” (appendix F.5). This notion of a facade pattern is described in a highly recognized book on object oriented designs (Larman, 2002). Larman (2002) explains that common and unified interfaces are needed to avoid undesirable coupling between different subsystems. He suggests a single point of contact for a subsystem called facades or “frond-end” objects that represent a single unified interface layer that collaborates with other subsystems. This decreases the impact of new components on existing components.

3.6.5 Conclusion

The European implementation processes show the evolving nature of ERTMS and changing requirements from involved stakeholders. To deal with this, the implementation of ERTMS must focus on various measures. First, cooperation and coordination is necessary between stakeholders. Second, besides the technological focus, the implementation of ERTMS requires an operational focus as well. Third, to form an environment where changes can be anticipated and implemented, a close cooperation with European innovation, standardisation and modularity programs and initiatives is advised. One important factor is to ensure facade patterns between components that are likely to change. These patterns allow systems to be loosely coupled so the effect of any changes for systems beyond the facade are limited.

3.7 Adaptability factors

This chapter describes various critical issues on the implementation of ERTMS. Table 8 provides an overview of the issues gathered in this analysis of the ERTMS basics that affect adaptability. These issues are merged when they occur multiple times throughout this analysis. They are also merged based on their common ground into various factors. These factors are then used as base for formulating proposed solutions in chapter 6.

Table 8: Critical issues identified in this analysis that trigger ERTMS adaptability towards the future

Factor	**Description of critical issues**
Technology updating	Due to the evolving nature of ERTMS, it is important to limit the negative effect if a new update proves to be of insufficient maturity (section 3.6).
	Marginal but necessary technological changes are considered expensive (sections 3.6).
Standardisation	ERTMS baselines of on-board equipment and trackside equipment and ETCS application levels are not fully compatible with each other (sections 3.3 & 3.6).
Modularity	To enable modularity, facade patterns can be used whereby systems are loosely coupled such that either system is little affected by changes “beyond the facade” (section 3.6).
Stakeholder involvement	The positioning of the program ERTMS could affect the balance in served interests between different stakeholders (section 3.5).
	The implementation of ERTMS affects various aspects and stakeholders, thus requiring coordination and cooperation (section 3.6).
Operational compatibility	The current focus of the ERTMS implementation is on technology, but it has a large effect on operational aspects as well (section 3.6).

4. ERTMS development analysis

This chapter provides an analysis on future developments. To gain insight in the effect of a development, a comprehensive conceptual model is created which is provided in section 4.1. This model provides information on the functionalities of components and interfaces of the Dutch ERTMS implementation. Section 4.2 will analyse foreseen innovations and provide a variation of the conceptual model in which an innovation is inserted, thus providing information about the effects. Thereafter, in section 4.3, an analysis of the overlap between the innovations will be provided. Section 4.4 describes financial and regulatory developments that affect ERTMS. These three section provide insight in the uncertainties and bring clarity in the critical issues for future adaptability of ERTMS. Finally, section 4.5 will conclude by providing these critical issues that influence the adaptability of the Dutch implementation of ERTMS towards the future.

4.1 Conceptual model

This section provides the conceptual models created for the planned Dutch ERTMS implementation and the generic ERTMS implementation. In section 4.1.1, the method used for modelling is explained. Thereafter, the conceptual model itself is shown in section 4.1.2 accompanied by the input and output relations of the most important components. Finally, in section 4.1.3, additional notes are added to the conceptual models. Certain design choices are explained here.

4.1.1 System Modelling Language (SysML)

A semi-formal method to visualize a system is System Modelling Language (SysML). SysML is a dialect to the known Unified Modelling Language (UML) and can be used for explaining a systems architecture (SysML, n.d.). This method gives insight in the data flow between components of a system. For instance, the movement authority generated by the RBC and ultimately used in the decision making process of the train driver. The SysML model provides insight in the various components that are required for this process. Furthermore, the various components can be categorized in different systems like GSM-R Network, track side and on-board equipment. These characteristics make SysML perfectly suited to model the ERTMS implementation (Ferlin et al., 2016).

4.1.2 Planned Dutch ERTMS implementation

To provide further insight in the planned Dutch implementation of ERTMS, two main conceptual models are created. The first is a model of a generic implementation of ERTMS, which is shown in Figure 10. The second is of the planned Dutch implementation of ERTMS. This model is shown in Figure 11. The innovations mentioned in section 4.2 which are taken into account, each have their own variation given in Figure 12 to Figure 17. As in section 3.4, a distinction is made between personnel, non-vital control components and vital safety components. Each component that is responsible for ensuring that safety measures are respected falls within the latter classification. The model is based upon various sources due to the conceptual nature of ERTMS:

- **ERA Specifications:** As base for the model, the third TSI (B3R2 / SRS 3.6.0) with ETCS L2 is used (ERA, 2019). While these specifications provide good input for on-board equipment, the specifications for trackside equipment as a whole is more open for interpretation (appendices F.1 & F.5). As the interviewed ERTMS experts states:

  > "Due to the nature of the ERA specifications, with their focus on train side equipment, the track side equipment is not specified allowing flexibility and versatility. A

drawback is that it is not an unambiguous standard and rather complex throughout Europe." (Appendix F.1).

This statement counts especially for the structure of the planning system and the TMS because ETML is not established yet.

- **Dutch ERTMS Program:** In order to tailor the implementation to the Dutch situation, sources from the Dutch ERTMS program and ProRail are used. The first is the ERTMS traffic system architecture provided by the ERTMS program (Programma ERTMS, 2018). The second is the technical reference for the architecture used by ProRail (ProRail, 2018).
- **Glossaries:** Various definitions are gathered using glossaries from the ERA and ProRail (ProRail, 2005; ERA, 2019).
- **Experts:** Finally, to finalize the conceptual model, various experts have been consulted to provide their view on the formed structure. These experts are, among other, ProRail experts on ERTMS, ICT and TMS and a EULYNX data architect. The interviews with these experts are summarised in appendices F.1 to F.3 & F.5.

To give insight in the structure of the conceptual model, few components and their function, input and output are described below. These components are important for the functionality of ERTMS:

- **IXL:** The interlocking is a centralized vital component which provides logic in routes and points to avoid conflicting settings. The input for this is train detection through trackside or on-board equipment and instructions by the TMS. Using this input, the regulation of the rail network area take form. The output goes towards the object controller and the RBC which is used for further management of trackside and on-board equipment.
- **RBC:** The Radio Block Centre is responsible for providing vital trackside information to train equipment. One of the most important functions for the RBC is the generation of MA's. These are transmitted to the train using the GSM-R network. The input required for this generation are the instructions provided by the IXL system and instructions given by the PRL through ETIS.
- **PRL:** Procesleiding (Traffic Management) is a non-vital system that manages the allocation of rail infrastructure to train entities. The continuous input required is gathered and transmitted through the TCS. Thus, if any delay occurs, the PRL can adapt to a new scenario. Any discontinuous planning variations are inserted through DONNA, VOS, the dispatcher or the signal operator, which can alter train movement if necessary.
- **GSM-R network:** The GSM-R network is composed of two vital components. The GSM-R mobile which provides means of transmission to and from on-board equipment and the GSM-R fixed network which provides means of transmission to and from trackside equipment. These two components together provide a means for the RBC to receive on-board data and to transmit information and instructions towards on-board equipment such as a MA.
- **EVC:** The vital heart of the on-board ETCS equipment. This computer gathers data from the on-board equipment and calculates dynamic speed profile. With this, the EVC performs ATP supervision. This data is also transmitted to the DMI.
- **DMI / Train Driver:** The train driver evaluates train state based on visualizations on the DMI and executes speed control. The DMI visualizes the braking curve, current speed and location, target speed, the movement authority, train length and a potential warning if the train exceeds the ETCS braking curve.

The components of the model are categorized in different systems. Each of these systems and their definition are explained below:

- **Track side:** All equipment that is centralized or decentralized localized outside the train.

- **Planning System:** The system that composes timetables beforehand without taking actuality into account as stated by the interviewed TMS advisor of ProRail (appendix F.3).
    - **Traffic Management System (TMS):** The system that manages the rail network based on the composed timetable and occurring events, like delay.
        - **Traffic Control System (TCS):** The sub-system that translates the bi-directional data or instructions between PRL and the safety system.
    - **Infrastructure:** This category contains components that are constructed alongside the rail corridor. It consists of ETCS and legacy systems as well as safety and control components meant to ensure safety measures
        - **Central Safety System (CSS):** This contains centralized components that regulate the train movement through the GSM-R network using the RBC and the trackside components using the IXL.
- **GSM-R Network:** All components that are part of the GSM-R network which is used for transmitting bi-directional messages, as specified in the TSI (ERA, 2016).
- **Train side:** All equipment that is localized within the train itself.

4.1.3 Additional notes

ERTMS is a complex standard which requires further interpretation on trackside by infrastructure managers in actual implementation, as stated earlier in section 4.1.2. To make a conceptual model of the planned Dutch ERTMS implementation, assumptions and generalizations must be made. To give insight in these decisions, the following notes are added:

- **Train Integrity Monitoring:** In accordance to the planned Dutch ERTMS program, a TIM is added according to the statement of the interviewed ERTMS experts: “TIMs for passenger trains are part of the current ERTMS implementation program” and confirmed by the interviewed stakeholdermanager of NS (appendices F.1 and F.19). While this addition is not necessary to comply to the requirements written in the TSI ERTMS B3R2 with ETCS L2, the TIM is used for preparation towards ETCS HL3. Furthermore, in compliance with the conditions of ETCS HL3, not every train is required to have a TIM. The ERTMS program specifies it for passenger trains only (VTO-103) (Programma ERTMS, 2019). For this reason, a choice node is added that check if the TIM is available. If it is, then train integrity is provided by the train. Otherwise, the trackside equipment must determine train integrity. More information can be found in 4.2.1. According to the interviewed ERTMS expert, the TIM is connected to the EVC through the TIU (Bartholomeus, M. personal communication, June 09, 2020), thus giving the described vice versa between train equipment and ETCS equipment. Furthermore, the TIU does not use the data provided by the TIM but simply serves as connecting interface.
- **Central Safety System:** The interviewed ERTMS expert states: “The interlocking and the Radio Block Centre is provided together in the program. ProRail calls it the CSS (Central Safety System).” (appendix F.1). While this is not in direct compliance with the ERTMS/ETCS reference architecture specified in subset-026 of the ERA specifications, this is in compliance to the planned Dutch ERTMS implementation and recent technological trends. This is confirmed by four respondents (appendices F.1 to F.3 & F.5). While this integration functions optimal towards HL3, it decreases adaptability if the required functions from IXL or RBC change. This is confirmed by an extensive review on the ERTMS trackside tender for the Min I&W (DB-EC, 2019).
- **Automatische Bediening ETIS** (Automatic Control ETIS): The functionalities of ETIS are not strictly defined yet, so the required functions from the interface with PRL are not clear. ABE is still under development, even the name is not fully determined. According to an interviewed

expert, the interface is likely to be named as such (Ruessink, F. personal communication, May 01, 2020).

- **Switchable Eurobalises and Lineside Electronic Unit:** These components are normally only part when implementing ETCS L1. However, these components are implemented in the planned Dutch ERTMS implementation. With rail transitions, like the change from the Dutch legacy ATP system to ETCS L2, these components can provide a failsafe passage if the RBC cannot establish a fully reliable connection. Besides, these components are used on yards at, for instance, Kijfhoek and the harbour rail line (Bartholomeus, M. personal communication, June 09, 2020).
- **TROTS:** The placement of TROTS outside the TCS is determined on its functionality. It is defined as a management system as it controls nothing while it manages occupation identification. According to this reasoning, it is moved towards the TMS. This is in contrast with the interview with an expert of ProRail ICT that argued that TROTS was part of the TCS (appendix F.2). Its placement alongside ETIS and ASTRIS is to provide a clear hierarchical structure of the planning, management and control systems.
- **STM ATB:** There are three methods described in article 7.2.5 the TSI CCS that allow interfacing to legacy ATP systems (EC, 2016). The first method is interfacing an external STM in a standardised manner. The second method is insertion in the ETCS equipment or via a non-standardised interface giving a non-conform STM. The third method allows independent operation if the operators can guarantee that rail transitions can be executed conform the TSI requirements. Until now, two B3 STM ATB equivalent systems are on the market. The Alstom device currently fulfils the translation task without providing a standardised interface with the EVC, thus complying to the minimum requirements according to the second method. This unit has its own interface with the DMI and TIU according to the interviewed ERTMS expert (Bartholomeus, M. personal communication, June 09, 2020). However, to acquire an STM, the Dutch ERTMS program is acquiring and developing their own STM ATB to prevent a vendor lock-in by 1 of the two current suppliers (Alstom & Bombardier) and stimulate competition in ETCS tendering (Hoeberigs, 2019; Programma ERTMS, 2018). This STM ATB is constructed according to the first method and includes a standard interface to the so-called Profibus, the part necessary for the EVC to communicate in a standardised manner with STMs which is obligated by the TSI CCS (Programma ERTMS, 2019; UNISIG, 2015). The conceptual models are constructed conform the latter option with the ability for the STM ATB to utilize ETCS equipment data if in SN mode (ERA, 2016).

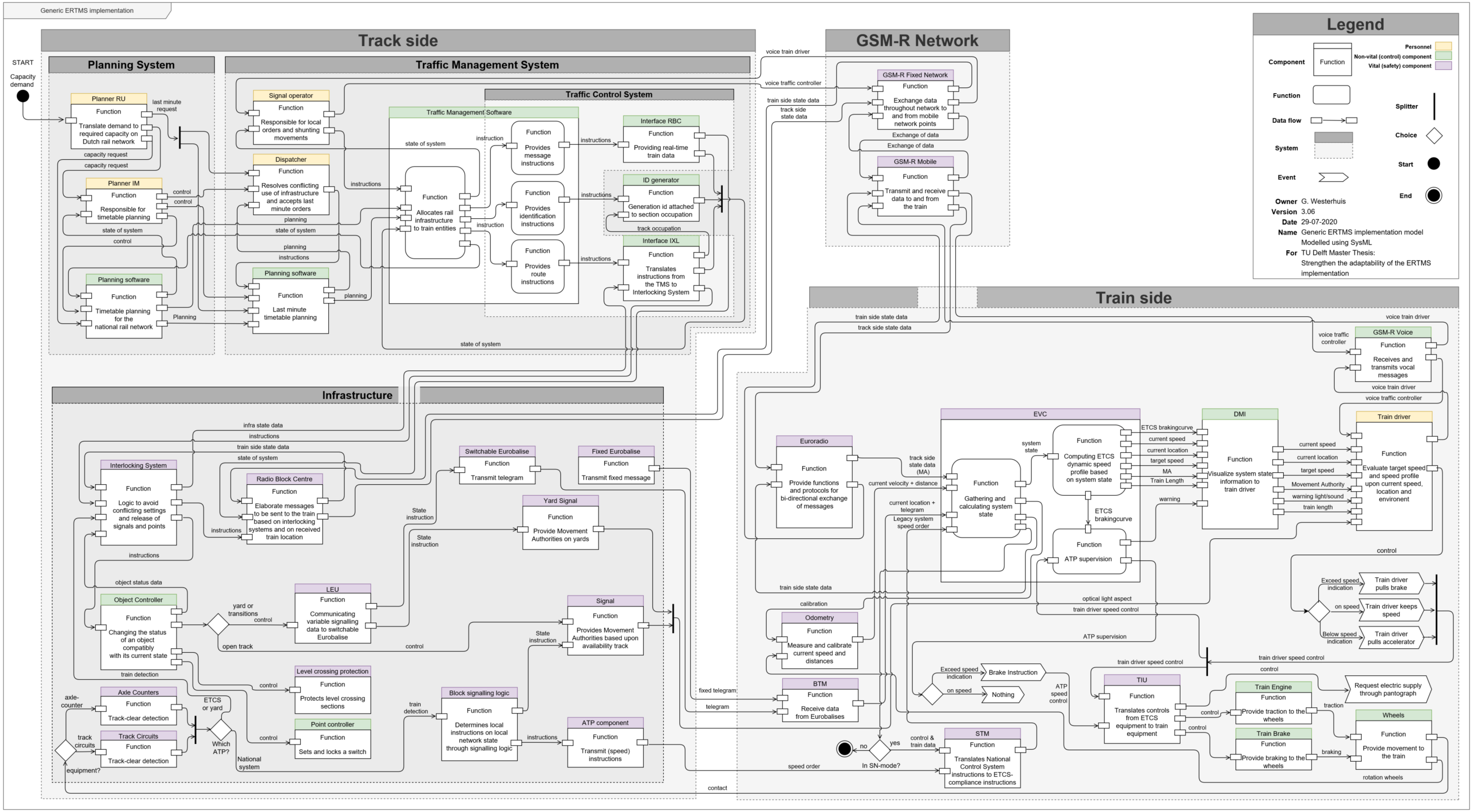

Figure 10: A generic implementation of ERTMS visualized using System Modelling Language.

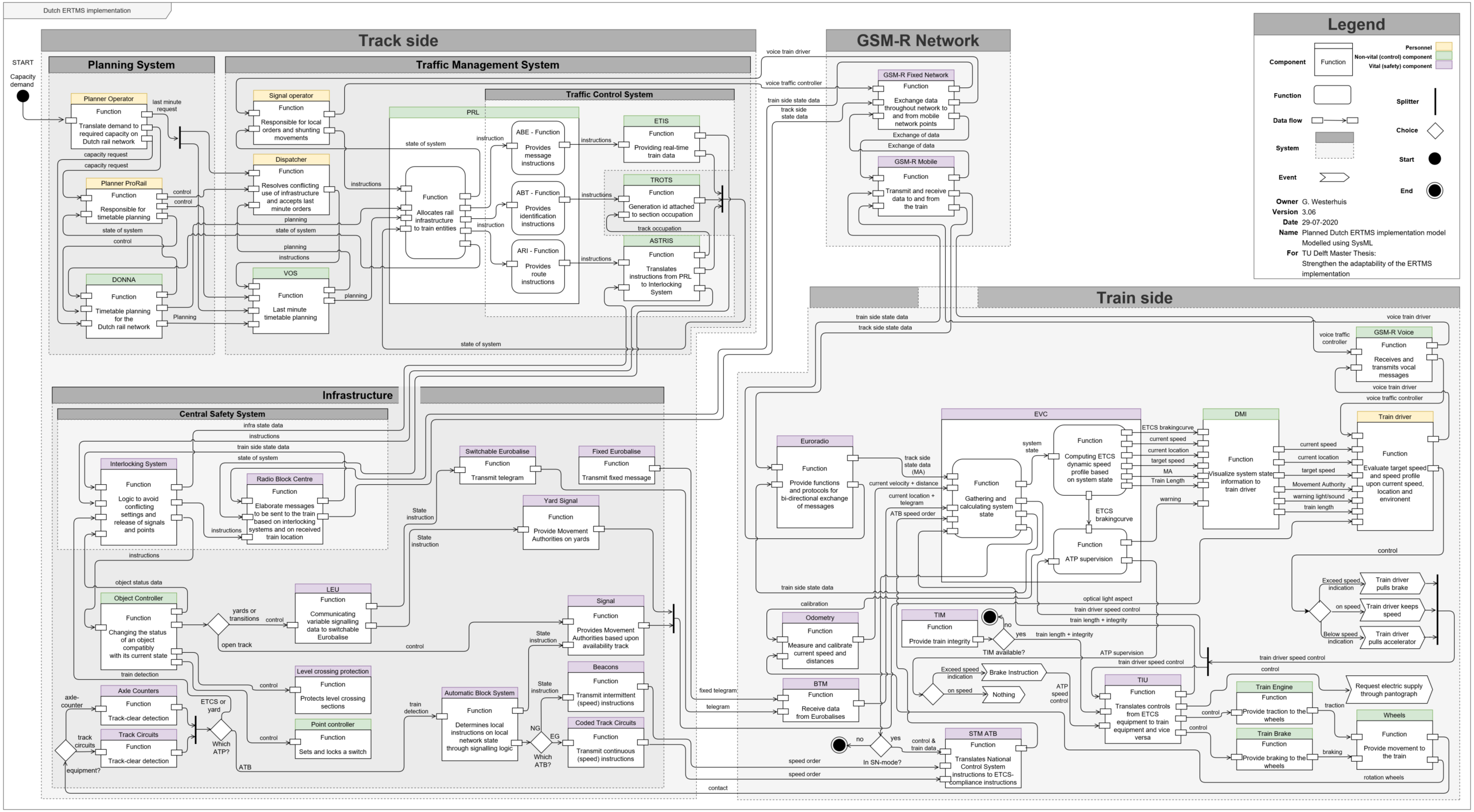

Figure 11: The Dutch implementation of ERTMS visualized using System Modelling Language.

4.2 Future innovations

This section describes the foreseen innovations that relate to the planned Dutch ERTMS implementation. This list will be formed using available literature and will be evaluated on their current configurability as stated in the technical specifications for interoperability from the ERA and the probability of their realisation. Each is coupled to their impact on the planned Dutch ERTMS implementation using a conceptual model. The impact is based upon available literature and the conceptual model described in section 4.1. The overlap and incompatibilities between the innovations is described is section 4.3. The innovations that are described in the following sections are:

- 4.2.1 - ETCS Hybrid level 3 (HL3) *Figure 12*
- 4.2.2 - 3kV railway electrification (3kV) *Figure 13*
- 4.2.3 - Future Railway Mobile Communication System (FRMCS) *Figure 15*
- 4.2.4 - New Traffic Management System (TMS) *Figure 16*
- 4.2.5 - Connected Driver Advisory System (C-DAS) *Figure 17*
- 4.2.6 - Automatic Train Operation (ATO) *Figure 18*
- 4.2.7 - Virtual Coupling (VC) with Vehicle-to-vehicle communication *Figure 19*

4.2.1 ETCS Hybrid level 3 (HL3)

An extensive description of ECTS application level 3, and of other application levels, can be found in appendix C. The main difference between ETCS application level 2 and 3 is the need for individual train integrity determined by on-board train equipment to allow virtual fixed or moving block sections (ERA, 2016). This can be achieved by fitting trains with a train integrity monitoring (TIM) system. While the most passenger trains of NS are already equipped with TIMs, this is technically more difficult to establish for freight operators (appendix F.19) (EUG, 2018). Establishing train integrity for freight trains remains a problem of achieving ETCS L3 without trackside detection. Furthermore, experts even think that this ETCS L3 is not realizable for the dense Dutch Network. The ERTMS expert states: "An useable version of the original Level 3, in which no trackside train detection was foreseen is not solvable/robust within the Netherlands." (appendices F.1). If a train would lose connection, it would be problematic. All local operation must be stopped in order for the RBC to localize the missing train. While ETCS L3 is always envisioned as ultimate goal, it might take more technical development before it is mature enough for implementation in the Netherland (RailEngineer, 2017; Programma ERTMS, 2019). ETCS L3 can be configured in four different variants; with virtual moving or fixed block and with or without trackside train detection.

A concept is developed based on the variant with fixed virtual block with trackside train detection. This concept, ETCS Hybrid Level 3 (HL3) is a mix of level 2 and 3 that utilizes fixed virtual blocks and thus decreased dependency on trackside systems (Furness et al., 2017). Hereby limiting the required usage of trackside train detection. Nevertheless, in HL3 this trackside detection will still be required so that trains that cannot ensure integrity with on-board equipment can still run on these corridors. Using this hybrid level, a corridor can be used by trains that operate under ETCS L3 and ETCS L2. As mentioned however, only fixed virtual blocks are possible. Because of the fixed trackside equipment, no utilization of moving block is possible. The conceptual model for this innovation is visualized in Figure 12. Further explanation can be found in the next paragraphs. While this concept is promising, it is only beneficial if a majority of the trains is fitted with TIM (EUG, 2018). Currently, the Dutch ERTMS program requested a TIM device in passenger trains (Programma ERTMS, 2019). This is confirmed by the Dutch Ministry of Infrastructure and Water Management and is validated by the interviewed ERTMS/ETCS expert and a stakeholder manager at NS (SpoorPro, 2017) (appendices F.1 & F.19). An upgrade to ETCS HL3 as bridge towards a ETCS L3 system with moving block is probable (EUG, 2018; Jansen, 2019). The ERTMS Users Group (2018) indicate that HL3 could be a pragmatic and flexible solution to start with. However, as mentioned, Dutch experts also suggest that HL3 could be a final goal. To implement ETCS HL3, various challenges must be overcome. Furthermore, these challenges serve as textual explanation to the graphical visualisation Figure 12:

- According to various researchers, ETCS HL3 requires high accuracy but especially reliable TIM devices on the majority of the trains on a specified corridor (EUG, 2018; Jansen, 2019).
- At first sight, from Figure 12, extra data is transmitted through the GSM-R network due to the addition of train length and integrity. The data required is Q_LENGTH and L_TRAININT. However, these are already being transmitted between train and track but with empty values (Era, 2016; Bartholomeus, M. personal communication, June 09, 2020). Thus, there is no impact on the GSM-R network and the EVC.
- While with ETCS HL3, trackside train detection and integrity equipment is still necessary, the amount required can be decreased. Which, in turn, increases reliability of the entire system due to redundancy of integrity equipment, both trackside and trainside.
- The RBC must fulfil an extra functionality by composing fixed virtual sections for other components to use (Senesi et al., 2018). Furthermore, the IXL requires information about these virtual blocks for setting and release of point and PRL through ARI and ASTRIS must be able to set routes using these virtual blocks.

4.2.2 3kV railway electrification (3kV)

As described in the introduction, a rather large portion of greenhouse emissions is caused by the transport sector. The train only contributes a small percentage to this portion. However, it could improve even more if rail operations run on 3kV, battery or hydrogen based. Each of these options could reduce energy consumption (ProRail & NS, 2018; Molyneux et al., 2010; Alstom, 2018). According to article 7.5.1.78 in subset-026 of the ERTMS TSI B3R2, the traction system voltage is configurable within the system (ERA, 2016). However, questions must be asked about the actual adaptability of the system if the supply on the national railway network would change towards 3kV. Especially because it is highly probable that this, or a similar transition will be happening within the Netherlands in the coming decennia (ProRail & NS, 2018). In other words, is a voltage change really configurable in ERTMS in such a way that it is adaptable? More information can be found on adaptability in section 4.4.2 with respect to the changeability of an ERTMS parameter. According to an interviewed ERTMS/ETCS expert, configurability of 3kV within ERTMS is an easy task due to the ability to configure the voltage setting both trackside and trainside. He states: “The change towards 3kV is not problematic for the ERTMS implementation. These are not national values but configurable values on the trackside and the trainside”. (appendix F.1). If the overhead electric lines provides 3kV and the pantograph, which is outside the scope of ERTMS, can handle the provided voltage then it is just a simple change in the configuration of the safety system. The conceptual model in Figure 13 confirms this by providing a visualization of the impact of 3kV on the planned Dutch ERTMS implementation. Furthermore, the train driver must cope with the changed driving rules due to faster acceleration and regenerative braking.

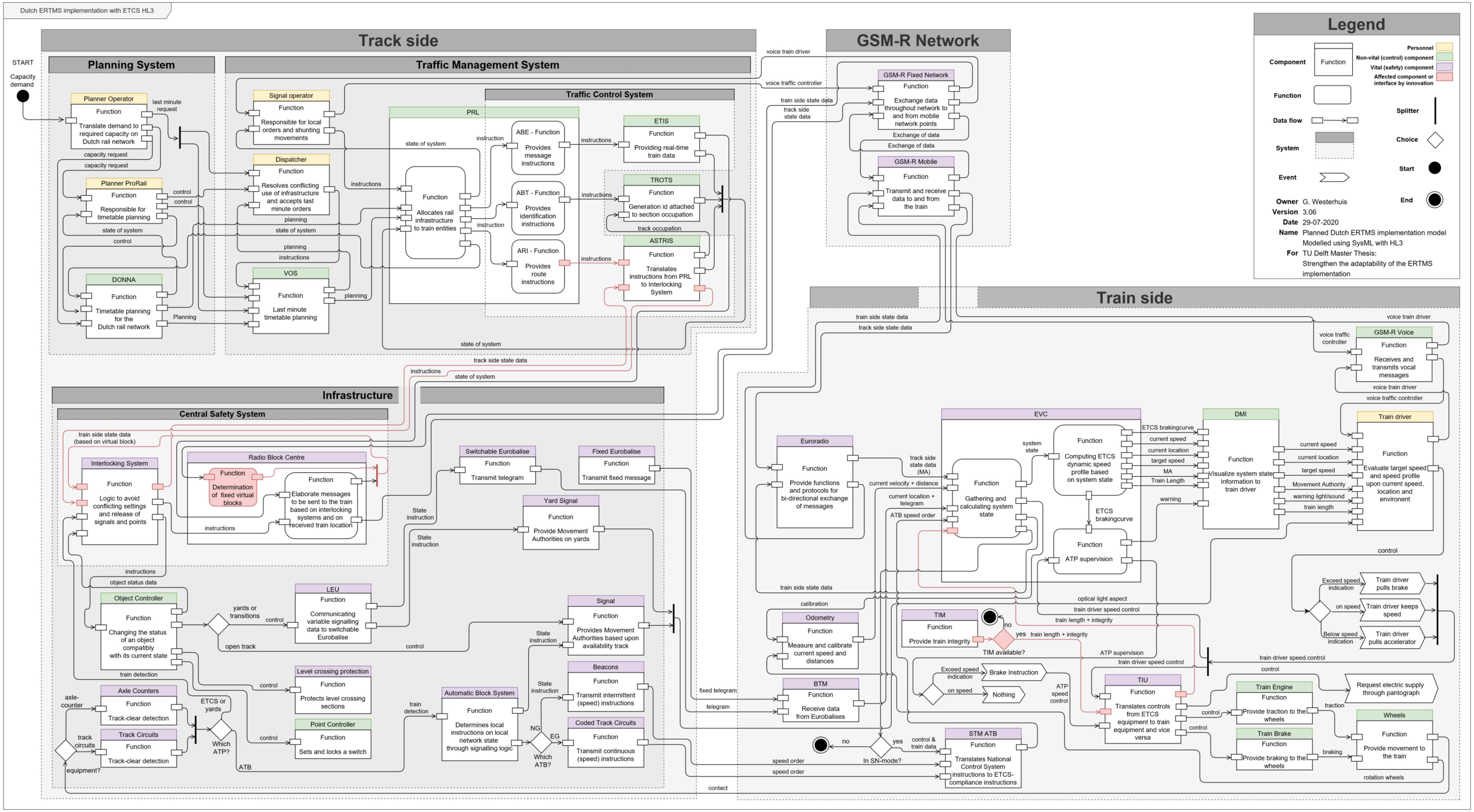

Figure 12: The planned Dutch implementation of ERTMS with ETCS hybrid level 3 implemented

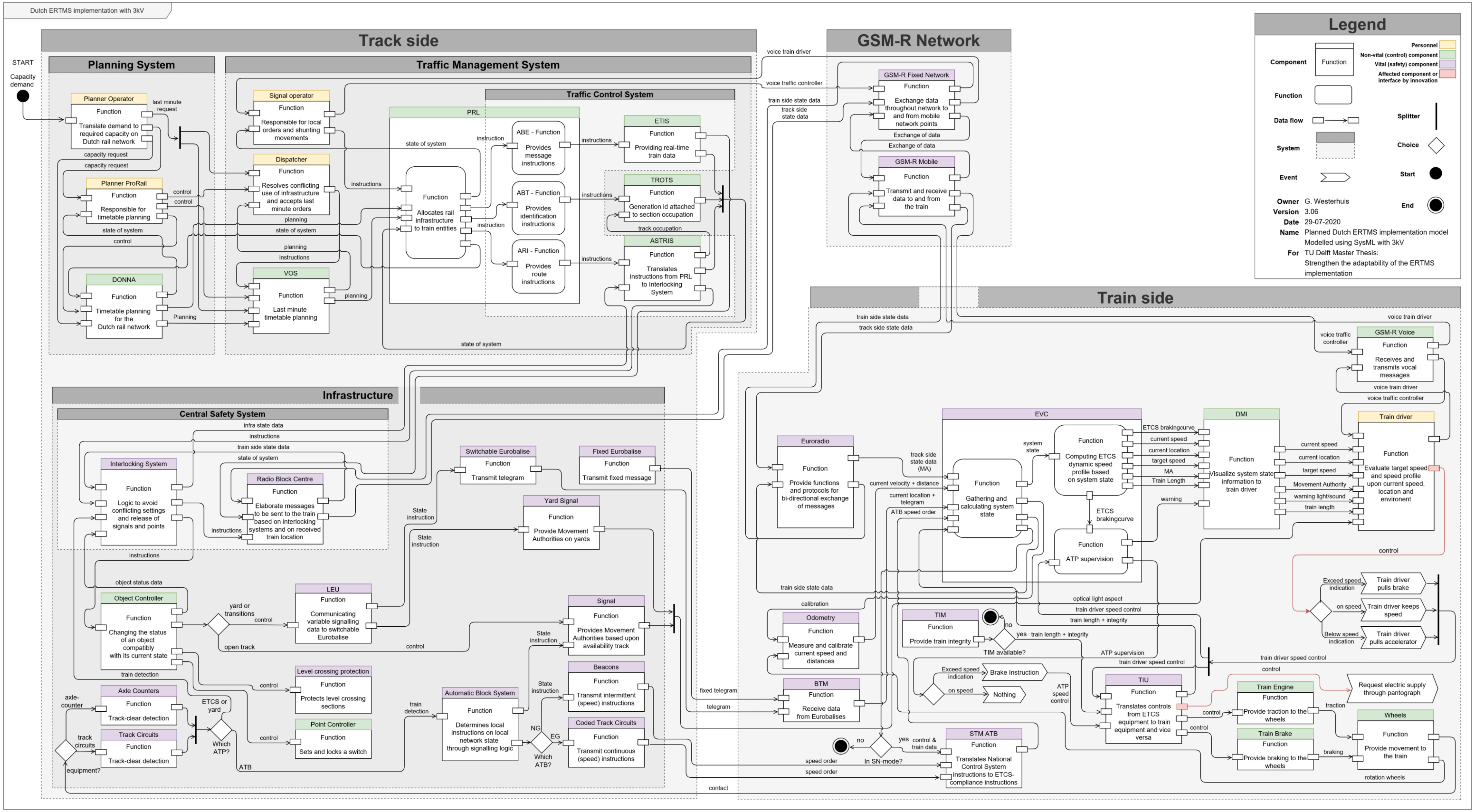

Figure 13: The planned Dutch implementation of ERTMS with 3kV implemented

The two other transition possibilities are assumed that they are not preferred by the involved stakeholders on a large scale within the Netherlands. This assumption is based upon the many researches done with respect to the transition to 3kV and pilot projects with hydrogen and battery powered trains (ProRail & NS, 2018). The latter would also have a very lengthy transition time. Besides these two options, a migration towards diesel powered engines is possible. However, due to environmental reasons, various of these trains in the Netherlands have been or are going to be replaced by electric versions (Turbantia, 2020; OVPro, 2019). Thus all these options are put outside the scope of the research and are not researched further.

4.2.3 Future Railway Mobile Communication System (FRMCS)

The planned Dutch ERTMS implementation is based upon GSM-R. However, support by the industry for GSM-R ends between 2028 and 2030 (EIM, 2019). Therefore, before that time the communication system should be prepared towards a next generation network system (ProRail & NS & Min I&W, 2014). Before this can happen, a standard for this next generation network system must be issued by the ERA. The new TSI expected in 2022 is likely to provide a migration strategy and alternative for GSM-R (Ruete, 2020). All three current sets of specifications are based upon a single baseline of GSM-R (ERA, 2019). To ensure uniformity and interoperability, a standardised solution must be awaited. There are various possible successor systems within view. However, the most likely to be inserted in the next set is the Future Railway Mobile Communication System (FRMCS)(ERA, 2018; UIC, 2020). Recently, the UIC released two important draft documents on FRMCS specifying the requirements for on-board equipment and migration scenario's (UIC, 2020). However, these are confidential and are currently not published online. The ERA (2018) suggest in their research that a fast switchover from GSM-R to FRMCS will be impossible and that it could take up to a decade. Besides, in the current situation, infrastructure managers see little point in investing in GSM-R, a nearly obsolete technology. The ERA (2018) also suggest that FRMCS must be based on a 5G platform. It is clear that the FRMCS solution is still under development. There are still various speculations on the system. However, its expected scenario would be a multimode on-board, supporting legacy systems (Figure 14) (EIM, 2019).

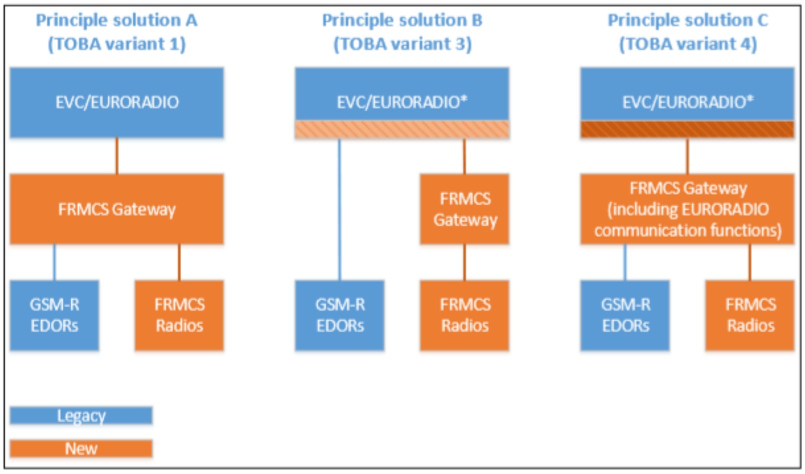

Figure 14: FRMCS Telecom On-board architecture solutions proposed by EIM (2019)

A recent position paper by the EIM (2019) provides three principle solutions (Figure 14) based on the solution given in a recent document of UIC on migration variants (UIC TOBA WG, 2019). Two solutions (B and C) touch the EVC/Euroradio, which makes these decreasingly suitable for existing trains with ETCS due to necessary corresponding costs. The first solution integrates a FRMCS gateway which translates both incoming and outgoing signals to an EVC/Euroradio compliant signal, thus leaving the EVC/Euroradio untouched. When metaphorically implementing all three solutions into the conceptual model, it becomes clear that solution B has the least impact on the planned Dutch ERTMS implementation. This exercise is visualised in appendix E. Thus, this solution is preferred if new train equipment is tendered. If an existing train require an upgrade for FRMCS, solution A is preferred. For this thesis, solution B is chosen as principle to take into account. As result, the following challenges must be overcome when implementing FRMCS:

- An entire network must be setup that can provides at least similar bandwidth with equal functionalities as the GSM-R network.
- An interface must be installed between the RBC and FRMCS network.
- To allow trains to operate within the GSM-R and FRMCS network a multimode on-board is suggested by the European Rail Infrastructure Managers (EIM). The main solutions suggested all rely on an additional FRMCS gateway that translates the signal into one that is usable for the EVC (EIM, 2019). The conceptual model in Figure 15 is mainly based on solution B as mentioned earlier. This gateway also functions as facade which improves adaptability as described in section 3.6.4. The Euroradio requires an adaptation to utilize the FRMCS signal.

Due to the high impact and high probability of a mandatory migration towards a new communication system this is taken into account into this research. The conceptual model of the integration of FRMCS in the planned ERTMS implementation can be found in Figure 15.

4.2.4 New Traffic Management System (TMS)

A TMS has various objectives. It sets routes for trains and detects and solves conflicts by continuous train movement monitoring (Thales, 2020). Currently, this task is performed in the Netherlands by PRL (ProRail, 2019). However, if various innovations which are described throughout this section are implemented, PRL must be able to acquire real-time information while distributing this towards specific trains. This enables trains to perform accurately according to the required needs (Rao et al., 2012). The current Dutch TMS system, PRL, does not support this process and requires more computational power. As the advisor on Traffic Management states: “However, if more trains are going to operate on the network then these systems are no longer adequate. Other systems or updates must be implemented. We are currently doing research for another TMS.” (appendix F.3). Rao et al. (2012) suggest that an integrated TMS system will be more likely to be more appropriate for the future. The Swiss railway companies develop such an integrated system in the form of SmartRail 4.0 (RailTech, 2019). Due to the reasons mentioned a migration towards a new TMS is highly necessary if other innovations are implemented. These reasons are acknowledged by ProRail as mentioned, who are currently researching for another TMS (appendix F.2). Thus, it is appropriate to take this innovation into account in this research. A conceptual model that visualises the implementation of a new TMS can be seen in Figure 16. While its visual change in the conceptual model is small, it will integrate the thirteen PRLs into one integrated TMS according to the interview with the expert from ProRail VL (appendix F.3). This does not have a direct effect on the functionalities required from the TMS, but it does have an effect on the components that are interfaced with it such as VOS and DONNA. These systems must convey their planning to one centralized TMS instead of thirteen decentralized systems. It is likely that the software interfaces such as ARI and ASTRIS limit the effect of this migration on interfaced safety systems as stated by the expert: “Because these interfaces translates TMS controls to the safety system and vice versa, the TMS is rather future-proof.” (appendix F.3).

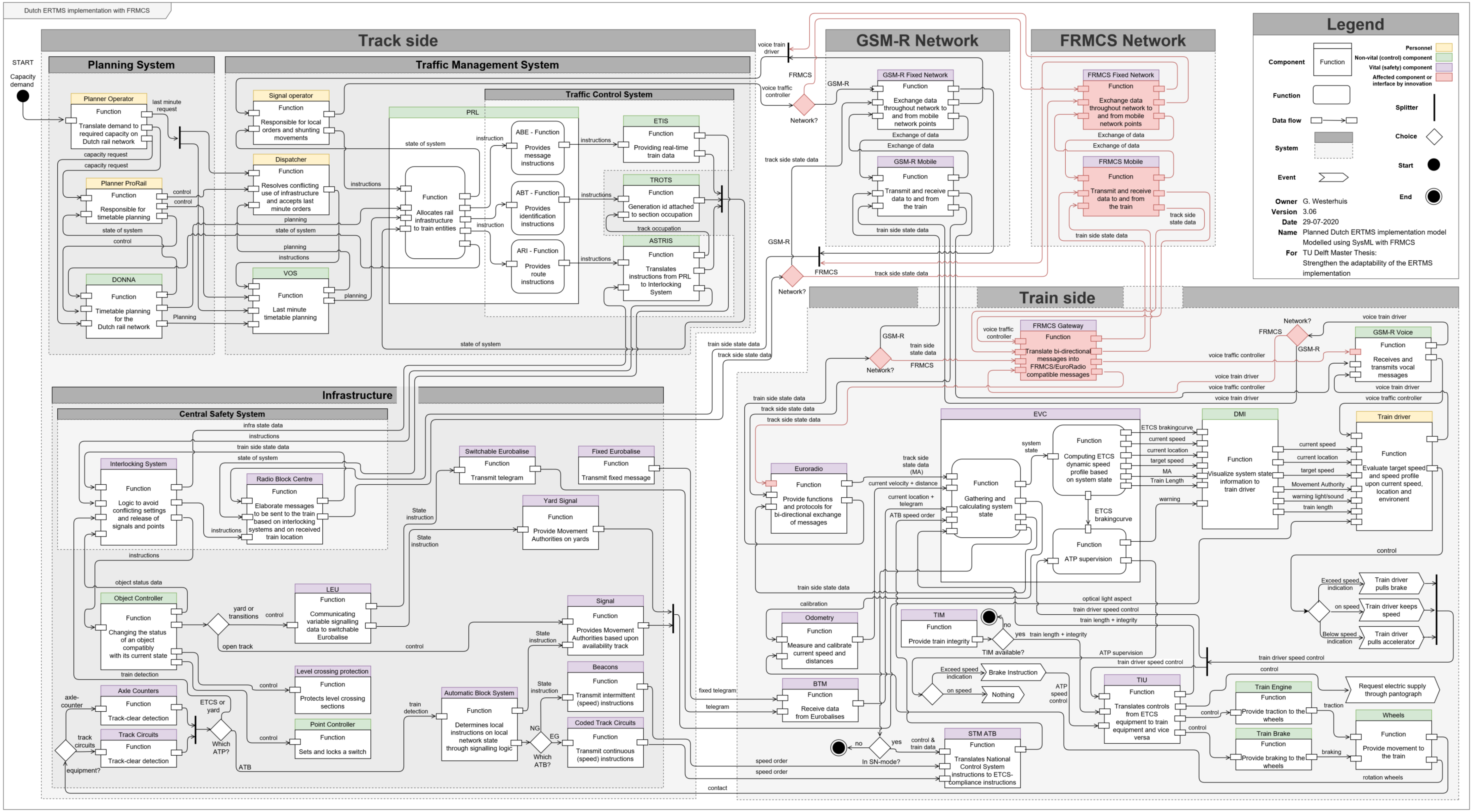

Figure 15: The planned Dutch implementation of ERTMS with FRMCS implemented

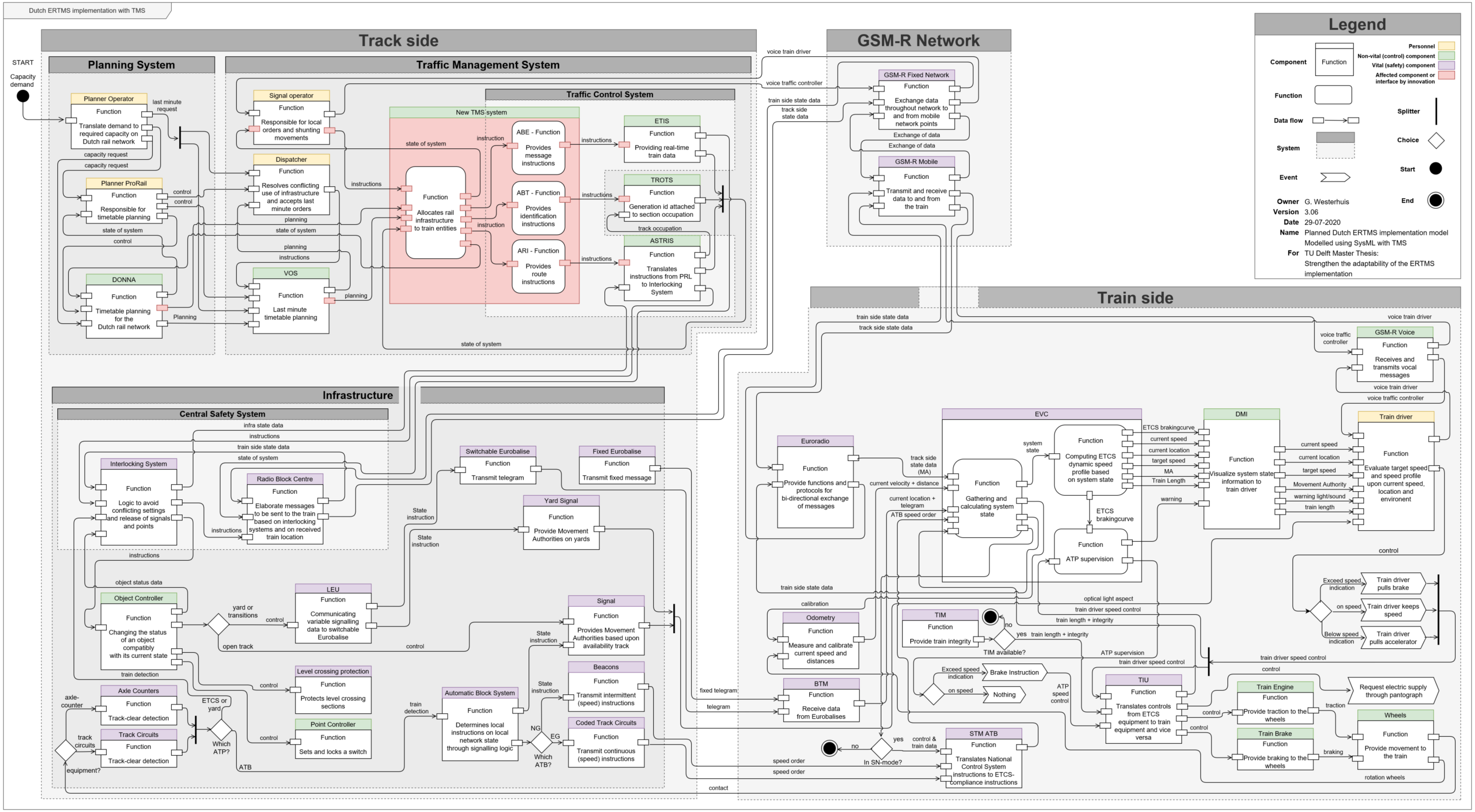

Figure 16: The planned Dutch implementation of ERTMS with a new TMS implemented

4.2.5 Connected Driver Advisory System (C-DAS)

A C-DAS is an extension to the general DAS system. A DAS can have various objectives on which it formulates advice to the train driver. An example of this is the search for means of reducing energy consumption of individual trains while ensuring punctuality according to the timetable (Tschirner et al., 2013). This is executed in the form of a Standalone DAS (S-DAS) or Networked DAS (N-DAS). These systems provide guidance to the driver based on the schedule. A drawback of these systems is that it optimises the performance of a single train as it would if this train was in isolation (Digital Railway, 2019). The C-DAS broadens the input by providing a bi-directional communication link between the on-board DAS and the TMS. This allows real-time optimisation with regard to, for instance, scheduling, punctuality, conflict avoiding or energy efficiency (Barrow, 2018), thus optimizing the performance of multiple trains through interconnection. However, a C-DAS is but a tool. It relies on the driver to utilize its potential (Leander & Törnblom, 2019). For this reason, a C-DAS is referred to as ATO with GoA 1. There are various challenges that must be overcome with the implementation of C-DAS according to literature and the conceptual model described in section 4.1 (see Figure 17). These challenges substantiates the visual impact shown in Figure 17:

- According to the English C-DAS implementation plan from Digital Railway, a third-party data network can be used besides the implemented GSM-R network (Digital Railway, 2019). However, if the GSM-R network is used, then this system must be able to handle the extra data. The latter option is assumed in the conceptual model (Figure 17).
- The TMS must be setup in such a way it could provide the information to the train. In the conceptual model, this would mean that a C-DAS component must be added (Digital Railway, 2019). This component gathers real time schedules and track data from PRL and calculates train targets that are transmitted to the train.
- A C-DAS component must be added in the train to process received data and provides location forecast status to the C-DAS trackside component. To formulate this, input is required from the EVC or at the journey start by the driver. In the conceptual model, it is assumed that an interface with the EVC is setup (Digital Railway, 2019).
- The C-DAS must be able to provide its advice to the train driver. This requires a dedicated HMI (Human Machine Interface) (Digital Railway, 2019). The interviewed ERTMS expert indicated that the ETCS DMI has no option to support a C-DAS (Bartholomeus, M. personal communication, June 09, 2020).

Due to reasons mentioned above and with respect to the innovation phase of the C-DAS system it can be assumed to be introduced to the Dutch market in the coming years. This makes it appropriate to include this innovation in the research. A conceptual model of the C-DAS implemented can be found in Figure 17. This model is based on the C-DAS System Boundary and C-DAS reference architecture composed in the C-DAS system definition by Digital Railway (2019).

4.2.6 Automatic Train operation (ATO)

Use of ATO enables trains to operate while depending less on train personnel and more on automatic systems. ATO is categorized by the International Association of Public Transport into four grades of automation (GoA) (UITP, 2012). The higher the grade, the higher the dependence on automatic systems until, with GoA 4, the train can operate autonomously and does not require on-board personnel (ASTRail, 2019). The research into ATO over ETCS is ongoing. In the latest released TSI (B3R2), ATO is not included. However, UNISIG composed a draft document called subset-125 which describes ATO over ETCS (Bienfait, 2019). However, this subset is currently not yet officially accepted and issued by the ERA (Simmons & Furness, 2019). This subset is only available as collection of draft documents for pilot projects. However, on these draft documents, the interviewed ERTMS expert states: “It is true that the specifications ATO over ETCS are not officially released. However, 95% of the specifications are already made.” (appendix F.1). According to Jens Holst Møller, chief engineer in Denmark’s rail infrastructure manager Banedanmark, the official standard for ATO over ETCS is expected by 2022 (RaiLTech, 2019). This is confirmed by the European ERTMS coordinator (Ruete, 2020). This will be part of the next set of TSI (ERA, 2019). This standard will replace the draft subset-125. The impact of ATO over ETCS is extensively described in a recent master thesis which relied heavily on this draft subset-125 (Buurmans, 2019).

According to English rail engineers Simmons & Furness (2019), the United Kingdom is preparing to implement ATO with GoA 2 widely throughout the national network. The UK already has two operational corridors that operate on GoA 2. One of these is the ThamesLink that opened in 2018 which connects the north and south of London (Barrow, 2018). GoA 2 requires the driver to close the train doors and operate the train in the event of a disruption. However, setting the train in motion, the driving and stopping is automated (UITP, 2012). For these reasons, ATO with GoA 2 is taken into account in this thesis. According to literature and the conceptual model from section 4.1 and Figure 18 there are various challenges that must be overcome:

- As stated, the ATO over ETCS specifications are not yet included in the official TSI. To ensure an uniform and unified rail network, it is important that these specifications are used instead of devising an own plastered solution.
- It is still unclear if the current GSM-R network is able to provide enough bandwidth for ATO GoA 2. While some sources argue that a new generation data network, such as FRMCS (section 4.2.3), is required (Toorn, 2019; Kessell, 2019). However, the interviewed ERTMS expert states: “GSM-R would provide enough bandwidth for ATO GoA 2.” (appendix F.1). This is confirmed by the pilot project on the ThamesLink, which is designed to operate on a GSM-R network (Hartwell, 2015). However, this network has been enhanced to meet reliability standards (Fletcher, 2019; Ricardo, 2019).
- The EVC must be able to provide the data to the ATO on-board component (RaiLTech, 2019). However, according to the Swiss Transport and Mobility Laboratory, ATO over GoA 2 can be operational by utilizing a message (ETCS Packet #44) that is already available through the EVC (Emery, 2017). However, it is important to wait for the official ATO over ETCS specification. Otherwise, every country will make their own adaptation of packet #44 which will result in a non-uniform an non-interoperable development (RSSB, 2017).
- Emery (2017) states that the main question in implementing GoA 2 is the corresponding human impact. How can train drivers be motivated and skilled if their task is reduced to initiate, supervise and potential interfering in an emergency situation? Emery (2017) argues for the solutions that drivers must be part of the process towards automation.
- Furthermore, for ATO to be more efficient, the ATO on-board should be connected to the trackside TMS through an ATO trackside component. This TMS should frequently transmit information which can be used to devise an optimal driving strategy (Siemens Mobility, n.d.). This is confirmed by the gamma version of the Reference CCS Architecture (RCA), which is an initiative of the ERTMS Users Group and the EULYNX consortium (EUG & EULYNX, 2020).

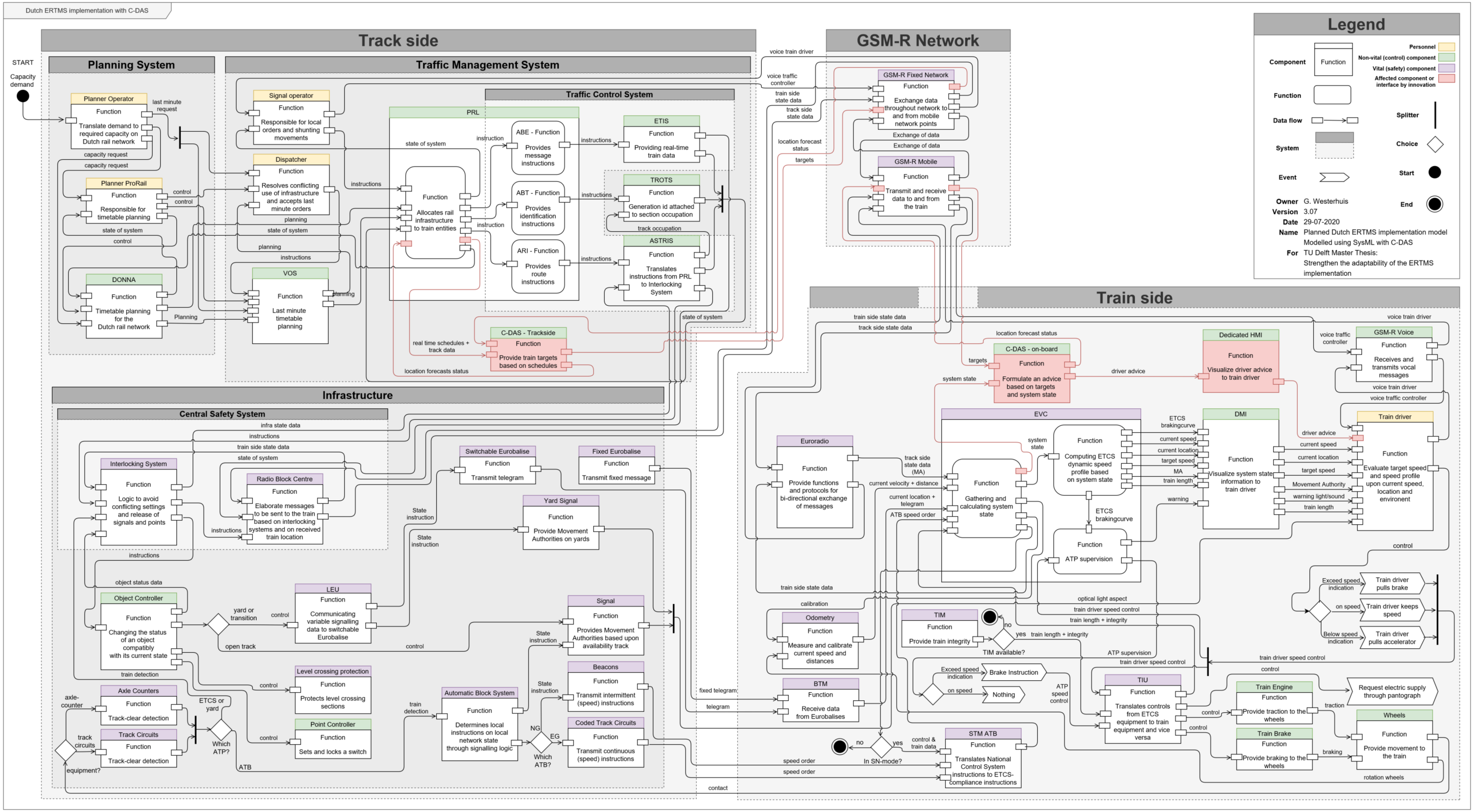

Figure 17: The planned Dutch implementation of ERTMS with a C-DAS implemented

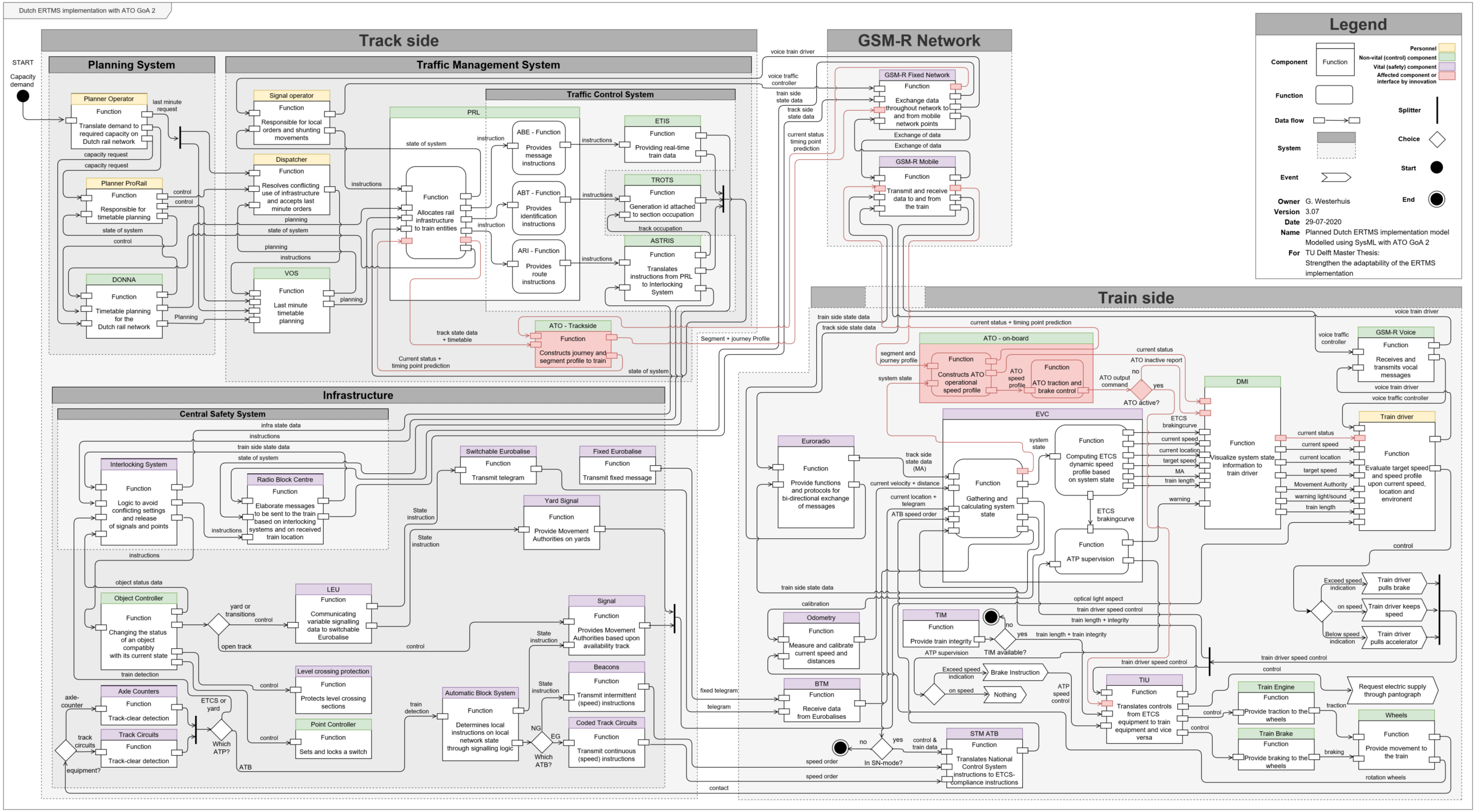

Figure 18: The planned Dutch implementation of ERTMS with ATO GoA 2 implemented

According to various high interest, high power stakeholders within the Dutch implementation of ERTMS, ATO is one of the goals that is made available through ERTMS (Toorn, 2019, ProRail, 2019, RailTech, 2019). Thus, the introduction of ATO with GoA 2 is taken into account in this research. The conceptual model that visualises ATO over ETCS in the planned ERTMS implementation is shown in Figure 18. This model is based on the Gamma Reference CCS architecture and the conceptual model on the Dutch system provided by Buurmans (2019) (EUG & EULYNX, 2020).

4.2.7 Virtual Coupling (VC) using Vehicle-to-Vehicle communication (V2V)

The railway sector is still unfamiliar with vehicle to vehicle communication. The current Dutch ATP system and its planned replacement, ETCS L2, both do not use this technological tool. In the automotive sector, this is different. Vehicle-to-vehicle (V2V) communication is widely recognised as automotive innovation on the agenda (NHTSA, 2017; Plungis, 2018). This technology could also prove to be a contribution to the Dutch rail innovation agenda. In some literature more specifically defined as train-to-train (T2T) communication. Fraga-Lamas et al. (2017) argue that inter-train communication still has many additional challenges besides the main challenge: the technical feasibility. These challenges are standardisation, interoperability and scalability. All these challenges must be addressed before an actual implementation can be executed (Fraga-Lamas et al., 2017). However, there are similar laboratory experiments performed which suggest that V2V communication is on the European innovation agenda (Shift2Rail, 2018). The potential benefits and possibilities of V2V communication is a discussion point between different railway experts (Quaglietta, 2019)(appendix F.1). V2V communication can be used to virtually couple vehicles as described in the MOVINGRAIL project (Shift2Rail, 2020). Virtual coupling enables the enhancement of the MA with kinetic data, such as speed, position and acceleration of the preceding trains instead of only providing the permission to run to a specific location. With this enhanced MA, trains can run in virtually coupled platoons, which improves capacity (Quaglietta et al., 2020). For this, a connection with the TMS must be made so that the TMS can form the platoons in the first place. This thesis implements virtual coupling that works similarly with adaptive cruise control. This requires the enhancement of the MA based upon the local train state data. According to literature and the conceptual model described in section 4.1 and in Figure 19, various challenges must be overcome. These challenges form also the textual substantiation for the graphical impact in Figure 19:

- An additional antenna must be inserted in the train to provide means to exchange bi-directional messages between trains.
- The EVC must be able to process the additional data to form an enhanced MA based on the provided MA by the RBC and the data from the other trains in the local area. Furthermore, this enhanced MA must be visualised on the DMI for the train driver to interpret.
- The corridor on which trains are virtually coupled, must operate on ETCS L3 with moving block. This setting requires the implementation of a TIM device in all trains.
- Furthermore, the IXL must be able to set and release points based on coupled trains instead of single trains.
- To allow bi-directional messages between trains, roles of stakeholders would need to change. Currently, railway operators are mainly in competition. With virtual coupling, a cooperative consortia might be necessary to compose and decompose train platoons to minimize required capacity (Shift2Rail, 2019).

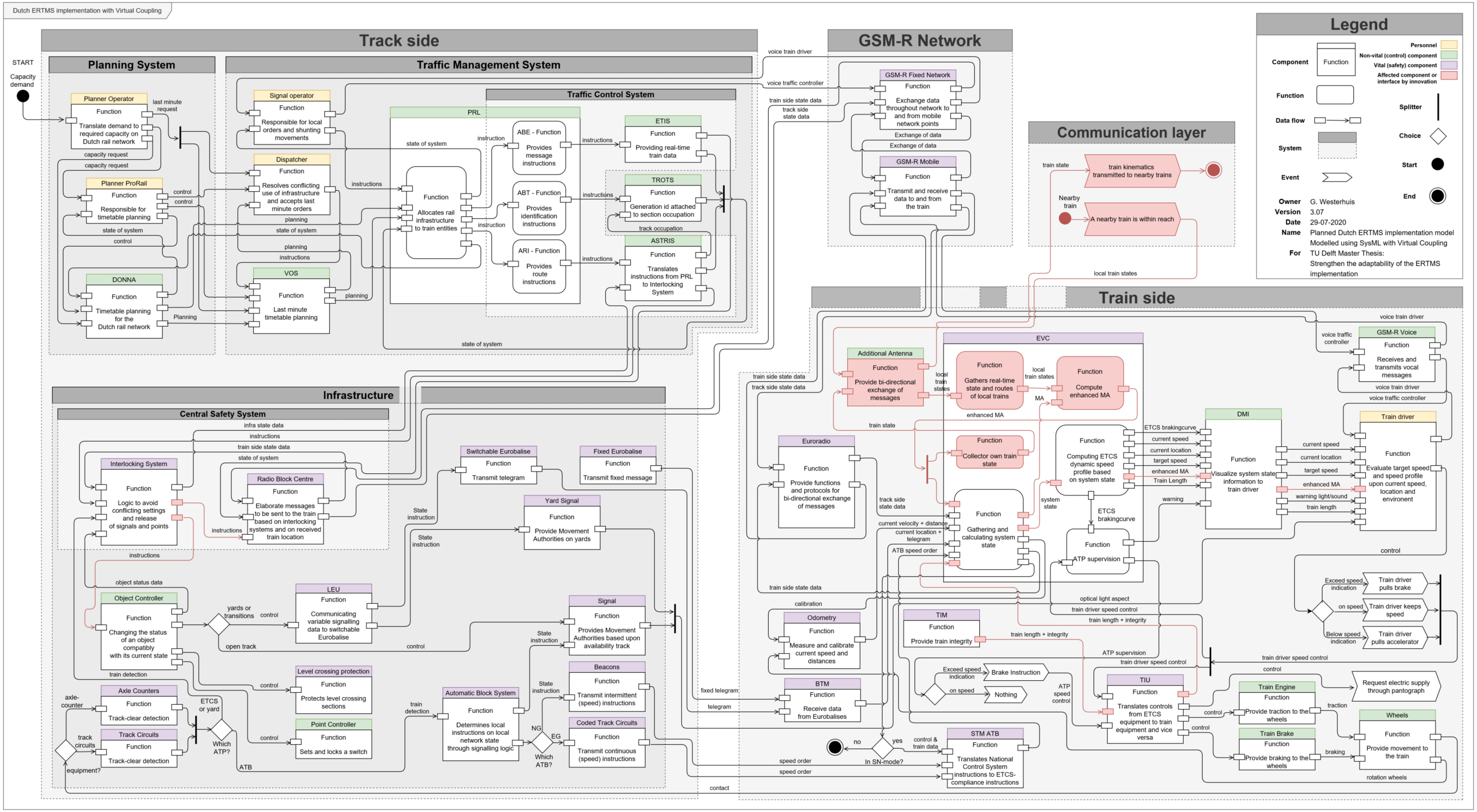

Figure 19: The planned Dutch implementation of ERTMS with Virtual Coupling using V2V communication implemented

Because of the reasons mentioned above, V2V communication with virtual coupling as described above is taken into account within this research. Figure 19 provides the conceptual model that visualizes the technology that allows an enhancement of the MA with kinetic data about the trains in the local network. This model is based on a recent research that utilizes V2V communication for virtual coupling while using ETCS L3 with moving block allowing separation with relative braking distance instead of absolute braking distance (Quaglietta et al., 2020).

Besides providing an enhanced MA, V2V communication could, in time, even function as new solution for railway signalling (Song & Schnieder, 2019). This is done by transmitting information to a train about the preceding train so a train could calculate their own MA. This solution would minimize the amount of trackside equipment by elimination of traditional train-detection devices. Furthermore, it minimizes the number of required centralized safety systems such as the IXL and RBC (Pascoe & Eihorn, 2009).

4.3 Impact and overlap of innovations

This section will describe the impact of the researched innovations on the planned ERTMS implementation and technological overlap between these innovations. Firstly, the impact on the on-board equipment is discussed (Table 9). Secondly, the impact on the trackside equipment and the communications network is discussed (Table 10). The final table discusses the overlap between innovations (Table 11). Each are visualized in a table. However, the latter is further substantiated with additional reasoning. The first two are extensively described in the various sections of section 4.2.

Each of the cells in the impact tables are categorized with a colour. The categorization of the impact is based on the constructed conceptual models in sections 4.1 and 4.2. These models visualize the impact of a certain innovation on the system. The categorization in tables is as follows:

- **No impact** *White* — The innovation has no effect on this component as visualized in the conceptual model.
- **Low impact** *Green* — The innovation has changed or added an interface with this component
- **Medium impact** *Yellow* — The innovation has changed or added a function within this component
- **High impact** *Red* — The innovation has changed or added multiple functions within this component

Table 9 shows the impact of the innovations on on-board equipment and Table 10 the impact on the trackside equipment and communications network. For example, the implementation of a new TMS has no effect on on-board equipment while the implementation of Virtual Coupling does. In turn, Virtual Coupling has no impact on trackside equipment or the communications network. Not all components are inserted in these tables. The components that are left out do not experience impact from the innovations or are represented by another component that is included in one of the tables. The substantiation of the tables is based on the innovations described in section 4.2 and their corresponding models.

Table 9: The impact of the researched innovations on the on-board equipment substantiated in given sections

Innovations	Sec.	Impact on on-board equipment: EVC	DMI	TIM	TIU	Train Driver
HL3	*4.2.1*	The EVC already can process TIM data		TIM implemented in the train	TIU creates the interface between the EVC and TIM	
3kV	*4.2.2*				Change in TIU parameter (M_VOLTAGE)	Different driving rules regarding acceleration and braking
FRMCS	*4.2.3*	The input from the Euroradio does not change				
TMS	*4.2.4*					
C-DAS	*4.2.5*	C-DAS requesting system state from EVC	An additional HMI is required but no impact on DMI			Additional input from C-DAS with the dedicated HMI
ATO	*4.2.6*	ATO requesting system state from EVC	DMI visualizes status ATO		ATO controls train through TIU	Additional input from the ATO on-board
VC	*4.2.7*	The EVC gathers train state and calculate an enhanced MA	DMI visualizes enhanced MA	The TIM is required for virtual coupling	TIU creates the interface between the EVC and TIM	Enhanced MA must be understood

No impact **Low impact** **Medium impact** **High impact**

Table 10: The impact of the researched innovations on the trackside equipment and the communication network substantiated in given sections

Innovations	Sec.	Impact on trackside equipment and communication network: VOS	PRL	RBC	IXL	Axle counters / track circuits	GSM-R
HL3	*4.2.1*		The PRL sets routes for virtual and physical blocks	The RBC must determine the fixed virtual blocks	The IXL must take virtual blocks into account	Less track-bounded devices required	
3kV	*4.2.2*						
FRMCS	*4.2.3*			RBC must use FRMCS to transmit track data			FRMCS replaces or coexists next to GSM-R
TMS	*4.2.4*	Output of VOS is transmitted to one TMS	PRL is replaced by this new TMS	No impact due to software interfaces	No impact due to software interfaces		
C-DAS	*4.2.5*		PRL provides schedules and track data				Real time schedules are additionally transmitted
ATO	*4.2.6*		PRL provides schedules and track data				Segment and journey profile are additionally transmitted
VC	*4.2.7*				Route must remain locked after platoon is passed		

No impact **Low impact** **Medium impact** **High impact**

Table 11: The impact of the researched innovations on implemented innovations

Innovations		**Impact on innovation that is implemented**						
	Sec.	HL3	3kV	FRMCS	TMS	C-DAS	ATO	VC
HL3	*4.2.1*	x						
3kV	*4.2.2*		x					
FRMCS	*4.2.3*			x				
TMS	*4.2.4*				x	New interface between C-DAS and TMS *(sec. 4.3.2)*	New interface between ATO and TMS *(sec. 4.3.2)*	
C-DAS	*4.2.5*			C-DAS requires bandwidth for schedules *(sec.4.3.3)*	New interface between C-DAS and TMS *(sec. 4.3.2)*	x	Interface HMI to ATO on-board *(sec.4.3.1)*	C-DAS on-board utilizes enhanced MA *(sec. 4.3.4)*
ATO	*4.2.6*			ATO requires bandwidth for journey profile *(sec.4.3.3)*	New interface between ATO and TMS *(sec. 4.3.2)*	Interface between TIU and C-DAS on-board *(sec.4.3.1)*	x	ATO on-board utilizes enhanced MA *(sec. 4.3.4)*
VC	*4.2.7*					Interface VC towards C-DAS on-board *(sec. 4.3.4)*	Interface VC towards ATO on-board *(sec. 4.3.4)*	x

No impact   **Low impact**   **Medium impact**   **High impact**

Next to the effect on the planned Dutch ERTMS implementation, the innovations have an effect on each other. Table 11 shows this impact and overlap. Additional reasoning can be found in the sections mentioned in this table. Each of the rows represent an innovation that is considered implementing. The columns represent the innovation that is already implemented.

4.3.1 Overlap between C-DAS and ATO GoA 2

The C-DAS and ATO GoA 2 are similar in functionality and layout in the conceptual models (sections 4.2.5 and 4.2.6). Both connect the TMS with the on-board equipment. The data that is transmitted through this connection is also alike. However, a C-DAS does not have an interface towards the TUI which is logical because it is only an advisory system. A C-DAS is a similar system to ATO GoA 1 due to the fact that all functionalities are performed by on-board personnel based, or not, on the provided advice. Therefore, the C-DAS could be used as bridge towards an operational ATO GoA 2. This would require the implementation of an interface between the on-board device and the TIU. According the conceptual models, if ATO GoA 2 is already implemented, it would require only an interface from the ATO on-board to the train driver through a dedicated HMI. While the implementation is rather easy, it would not be very effective because ATO GoA 2 already makes a C-DAS practically obsolete.

4.3.2 Impact on the TMS by C-DAS or ATO GoA 2

Both the implementation of a C-DAS and ATO GoA 2 would require an addition in the TMS (sections 4.2.5 and 4.2.6). Both the ATO and the C-DAS trackside require a bi-directional interface to the PRL. Optimally, this would be combined with the new TMS that is currently under research at ProRail according to the interviewed advisor of traffic management at ProRail (appendix F.3). This new TMS would integrate the current thirteen decentralized systems into one centralized system. This would improve the C-DAS and ATO GoA 2 theoretical performance due to the fact that a schedule or segment/journey profile could be based upon the entire network state instead of only a thirteenth part. Due to this reason, it would be better to add a C-DAS or ATO trackside component in the new TMS instead of requiring to replace and reconnect the components due to the redesign of the TMS.

4.3.3 Impact on FRMCS by C-DAS or ATO GoA 2

Both a C-DAS and ATO GoA 2 require bandwidth to transmit bi-directional messages between track and train. With both innovations, this transmission is between the TMS and an on-board component. A C-DAS and ATO GoA 2 would be able to operate through the GSM-R network as stated by the interviewed ERTMS expert: "GSM-R would provide enough bandwidth for ATO GoA 2." (appendix F.1) (Hartwell, 2015). However, this is disputed by other experts (Fletcher, 2019; Ricardo, 2019; Toorn, 2019; Kessell, 2019). It is not disputed that it does require extra bandwidth. Thus if one innovation is implemented after implementation of FRMCS, this has its impact on the network. FRMCS, on the other hand, would undoubtedly provide the environment that is required for utilization of a C-DAS or ATO GoA 2 (UIC, 2020). Thus its effect on ATO GoA 2 or a C-DAS if implemented is none.

4.3.4 Impact on Virtual Coupling by ATO GoA 2

A C-DAS and ATO GoA 2 optimizes performance of a train through the TMS by analysing the network state. By utilizing Virtual Coupling as described in section 4.2.7, its functionality is similar. Virtual Coupling is a more direct method to optimize performance based on nearby trains. V2V communication establishes a future-proof environment for more innovations. If Virtual Coupling is implemented, then the C-DAS or ATO on-board could utilize the enhanced MA to improve their own performance. If Virtual Coupling is implemented afterwards, it would need to provide an interface towards these innovations to transmit the enhanced MA.

4.4 Financial and regulatory developments

In this section, as described, various financial and regulatory developments affecting ERTMS are listed. These future changes are each described and coupled to their impact on the planned Dutch ERTMS implementation. The choice to take each change into account for the creation of the proposed strategy is supported with a reason based upon its likelihood and impact according to literature.

4.4.1 Change of responsibilities and functionalities of stakeholders

NS received its concession for the main rail net on January 2015 for 10 years (Min I&M, 2014). This directly awarded concession ends officially on the first of January of 2025. The European Commission, however, prefers competitive tendering above direct award for public service contracts (EC, 2017). The chosen method to create this envisioned competitive rail sector is to implement the fourth railway package. This package opens domestic passenger markets and disallows direct award for more than 10 years. Regulation (EU) 2016/2338 regulates this opening (European Parliament, 2016). However, from 2023 onwards Direct Award is only allowed if there is a performance exemption (van de Velde, 2018). This suggests that there could be a possibility that NS does not receive the concession for 2025-2035. However, the Secretary of State recently informed Dutch parliament on her intention to repeat the direct award for another period between 2025 and 2035 (Min I&W, 2020). Other public transport operators are opposed to this intention (NRC, 2020).

Besides the role of operator on the main rail net, the role of infrastructure manager could also be changing. ProRail, as infrastructure manager, is structured as an independent administrative body from the first of July 2021 (Rijksoverheid, 2020; van Veldhoven, 2020). This change is controversial within the railway sector. Various parties, such as freight and regional operators, are not optimistic about the change and are afraid that the performance and pragmatism of ProRail is decreasing as consequence (SpoorPro, 2020). However, according to the deputy secretary general of the Ministry of Infrastructure and Water Management, the structure change will not change anything in daily practice. While these are factors of high power, the actual change in responsibility has a very low probability as would the occurrence of the corresponding effect. Thus both the changes for NS and ProRail are not taken into account in this research.

4.4.2 Change of national value or parameters

ERTMS can be adjusted according to various parameters or national values. These values represent a configuration which enables specific usage in a specific environment. How changeable these values or parameters are is important to determine the adaptability of the implementation of ERTMS. According to the glossary of the TSI, national values are values which are transmitted to equipment of a train when entering the infrastructure of an administration. National values can be different between these administration areas (ERA, 2016). Examples of national values are: available adhesion, maximum emergency brake deceleration or release speeds. In other words, aspects that connect to, for example, allowable braking-curves and overlaps. National values improve flexibility and can thus improve performance in a specific railway network. These parameters can be set by the infrastructure manager (RSSB, 2019). According to the information given in the specification on national values, these values are transmitted by balise groups and overwrites the previous set of national values (3.18.2.8.1) (ERA, 2016). This description of national values is its theoretical functionality. In practice, trains require testing and certification based upon specific national values. In other words, a train operating in Belgium and the Netherlands is certified based on the national values of these two countries. If this train requires rerouting through Germany due to circumstances, which has another value for that specific national value, it would not be accepted and thus not allowed. If the Netherlands require a change in a national value, every international train that operates within the Netherlands must be tested and certified again. This is stated by the policy advisor of the Min I&W: "So, trains still cannot cross the border to a country with a different specified National Value, because it is not tested and certified for this different usage. This is clearly not stimulating interoperability." (appendix F.9). He suggests that: "… an entire range of National Values should be tested and certified to ensure operability between different countries".

The change of a parameter is different. These parameters are not transmitted by balises but are configured in the train or track. A very relevant example is the energy transition to 3kV described in section 4.2.2. While this energy transition is, in itself, not within the scope of ERTMS, its change must require a parameter, which is part of ERTMS, to change. This parameter is M_VOLTAGE (article 7.5.1.78 in subset-026 of the ERTMS TSI B3R2). This parameter is part of the track-condition package which is configurable according to the interviewed ERTMS expert as mentioned in section 4.2.2 (appendix F.1). Furthermore, article 7.5.1.78 specifies that the voltage is changeable based upon the traction system (ERA, 2016). Due to these reasons it will be no problem to adapt for the ERTMS system towards 3kV. The changeability of a national value and a parameter are described extensively in the interviews on the HSL-Zuid (appendices F.7 & F.9).

4.4.3 Not sufficient financial means for high cost of marginal technological change

According to the European Commission, the cost of marginal technological changes are rather high while member states provide not enough financial means for this (EC, 2020). This could mean that adaptability through minor technological changes is limited. Especially with a fast changing standard as ERTMS. An example is the change required on the HSL-Zuid (section 5.1). The set of specifications expected in 2022 might have such an impact (ERA, 2019; EIM, 2019). In other words, one must take into account that technology such as this keeps on developing and therefore require marginal technological changes to keep the system running in an optimal manner.

4.5 Critical issues

This development analysis of ERTMS provides various technical critical issues where adaptability for the Dutch implementation of ERTMS might be necessary in the future. Table 12 provides an overview of these critical issues. Some of these issues are merged when they occur multiple times throughout this chapter. These issues are merged and categorized on their common ground into factors to provide additional factors for the substantiation of the proposed solutions in chapter 6. All adaptability factors that are deducted throughout this thesis are described in section 6.1.

Table 12: Critical issues identified in this analysis that trigger ERTMS adaptability towards the future

Factor	**Description of critical issues**
Technology updating	Marginal but necessary technological changes are considered expensive (section 4.4).
Flexibility management	Vehicles that are certified with certain national values must be recertified if the applicable operational administration area changes (section 4.4).
Future needs	ERTMS is continuously evolving with changing technological and operational needs with the increasing possibility of implementing outdated components (section 4.2).
	The CSS, the IXL and RBC combi-system, in the planned Dutch implementation should be able to operate under ETCS HL3 (section 4.1).
	The train driver must be educated to handle various upcoming innovations such as the utilization of 3kV, a C-DAS, ATO with GoA 2 or the enhanced MA with virtual coupling (section 4.2).
	With the innovation ETCS HL3, the RBC should be able to determine fixed virtual block sections (section 4.2).
	With the innovation HL3, the IXL and TMS with corresponding software interfaces should be able to handle fixed virtual block sections (section 4.2).
	In order to use ATO or a C-DAS optimally, a bi-directional interface must be added in the TMS. Both should be added in the implementation of the new TMS (section 4.2).
	In order to optimally utilize ATO and C-DAS, the GSM-R network must be enhanced or FRMCS must be implemented to provide enough bandwidth for both innovations (section 4.2).
	The EVC must allow standardised interfaces to other components like an on-board ATO or C-DAS component to optimize their functionality (section 4.2).
	Preparation to add a FRMCS gateway into the on-board equipment with an interface towards an adapted Euroradio must be taken into account with new trains (section 4.2). With existing trains, a FRMCS gateway must function as facade between the GSM-R and FRMCS networks to the Euroradio (sections 3.6 & 4.2).
	The RBC must be able to connect to the FRMCS network in order to provide track state data, such as the MA, to the train through this network (section 4.2).
	The train on-board equipment must be prepared to implement a dedicated HMI to provide advice to the train driver based on the C-DAS (section 4.2).
	The DMI must be able to visualize the enhanced MA and data on ATO to the train driver (section 4.2).
	The TIU should be prepared to process data from the TIM device to the EVC (section 4.2).
	The TIU should be prepared for an interface with the ATO on-board to allow grade of automation 2 (section 4.2).
	In order to implement Virtual Coupling, the EVC must be adapted to receive and process local train data, establish an enhanced MA and transmit its own train state to other trains through the communication layer (section 4.2).
	In order to implement the communication layer for V2V communication to allow Virtual Coupling, an additional antenna should be implemented (section 4.2).
	For the innovation ETCS HL3 the implementation of a TIM device is desired. For virtual coupling, this implementation is necessary (section 4.2).

5. Case studies

In this chapter three case studies are performed in order to acquire knowledge about how the identified adaptability factors from section 2.5 influence adaptability in real-world examples. The chapter starts with the first case study which examine the HSL-Zuid, the High-Speed train corridor between Amsterdam and the Belgian border. Section 5.2 is about RouteLint, a Driver Information System (DIS) originally developed by ProRail to further optimize economical operation. The last of the case studies is about the implementation of the Dutch national travel smart card, the OV-Chipcard. This case study is described in section 5.3. The chapter ends with a summary of the adaptability factors confirmed by the case studies (section 5.4).

5.1 Case study I: HSL-Zuid

The HSL-Zuid, the High-Speed Line between Amsterdam and the Belgian border, opened in 2009 and is 85 kilometre. The project is part of the European high-speed train network and is meant for international passenger transport. The HSL-Zuid is constructed by Infraspeed under a DBFM contract (Design, Build, Finance and Maintain). This contract started in 1997 and is formally completed in 2031. With the construction phase technically ending in 2007 the 25 year maintain phase started. Due to the nature of the HSL-Zuid and this thesis it is appropriate to scan also the technicalities of the ERTMS implementation. The system originally implemented was ERTMS SRS 2.2.2. However, this baseline did not support interoperability between the Dutch and Belgian rail system. To mend this interoperability, a new unofficial baseline was developed: SRS 2.3.0 Corridor (Decisio, 2020)(appendix F.7). Currently, there is a discussion to upgrade parts of the corridor to B3 (Goverde et al., 2012; ProRail & NS, 2018). To acquire further knowledge about the adaptability of the HSL-Zuid project, employees of various stakeholders have been interviewed:

- Manager Contract Management Team of ProRail (appendices F.6 & F.10)
- Manager Operations of Infraspeed Maintenance BV (appendix F.7)
- Maintenance Engineer of Infraspeed Maintenance BV (appendix F.7)
- General Manager of Infraspeed Maintenance BV (appendix F.8)
- Policy Advisor of the Ministry of Infrastructure and Water Management (appendix F.9)

5.1.1 Adaptability in the project

This case, through the interviews, focusses on the following adaptability factors: flexibility management, stakeholder involvement and process clarity. After realization of the corridor, Infraspeed must maintain the HSL-Zuid for 25 years. In 2031 the concession ends and the maintenance of the HSL-Zuid is transferred to ProRail. However, Infraspeed must provide enough spare parts and warranty to guarantee operation until 2036. This DBFM contract is between The State and Infraspeed. However, The State does not have the expertise to perform supervision. Therefore, the task is delegated to ProRail CMT (Contract Management Team). A sketch of the governance model can be seen in Figure 20. Formally, no contractual lines exists between the operators, NS, Thalys and Eurostar, or ProRail and Infraspeed.

How well Infraspeed performs on the HSL-Zuid is mainly measured, by the contract, with two indicators. The first is the availability of the infrastructure (99.46% availability) and the second is the safety of the infrastructure (Hoogzaad & van Ham, 2006). These two indicators are measured, evaluated by a list of extensively described conditions and possibly fined. The evaluation of

Infraspeeds performance is calculated with the Performance Simulation Model (PSM) which includes a bonus that can be traded for bad days, so that penalties are compensated (Infrasite, n.d.). With this model, a “bonus-malus” system is introduced. However, the main mechanism that bad performance is penalized one way or the other remains. A respondent states: “If operation stops then we risk a fine of millions of euros.” (appendix F.7). In other words, if the track is not available for a single day due to problems which are a clear responsibility of Infraspeed (such as asset failure), then the corresponding fine could reach multiple millions if not compensated with bonus possibilities.

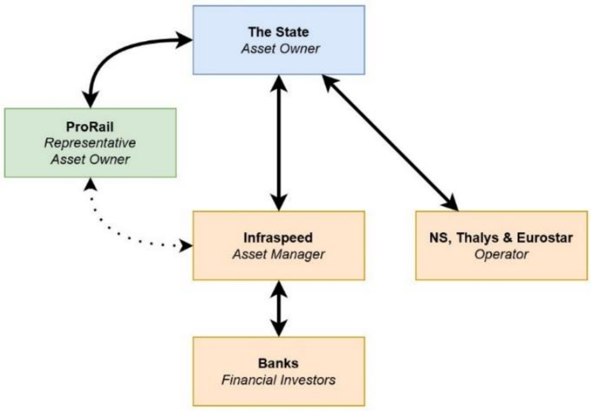

Figure 20: Simplified governance model HSL-Zuid between 2007 and 2031

This penalty system, which is perceived to be heavy, enforces Infraspeed to optimize safety and availability of the system. Logically, Infraspeed therefore want to minimize risks that could have a negative impact on these factors or minimize their responsibility over these risks, this is confirmed by Hoogzaad & van Ham (2006) who researched the exploitation of the HSL-Zuid. This is entirely in accordance to the contract structure that has been setup. However, with regard to the adaptability or changeability of the system this contract proves to be a hinder. This is also stated by one respondent: “Changing a component introduces additional risks which is not desirable for Infraspeeds point of view.” (Appendix F.7). This confirms the adaptability factor on flexibility management. A tool introduced to enforce changeability in the HSL-Zuid is the SVP (State Variation Proposal). A SVP is formulated by The State in cooperation with ProRail CMT that is given to Infraspeed. Infraspeed must comply to this SVP. The contract specifies three reasons that can be given by Infraspeed to decline a SVP. Summarized and freely translated, a respondent states:

> “If the change adversely affects the safety of the HSL Assets. If the intended change does not lead to obtaining the permission and / or license (from third parties) required for the implementation. If the change causes the infrastructure provider to lose its funding for the HSL Assets” (appendix F.10)

If these three reasons are not applicable but the SVP does potentially introduce additional risks, Infraspeed is likely to argue for exemption of these additional risks. This is stated by a respondent: “Infraspeed wants to minimize risks. If a change introduces additional risks Infraspeed will want to receive exemption for the risk or a risk contingency needs to be added to cover this risk. “ (appendix F.8). This contingency is based on the consequences of the risks: the heavy penalty system. Both consequences have their impact on the balance between costs and benefits for The State, increasing the reason to recall their SVP. This mechanism is confirmed by the examples in the interviews and is confirmed by examples provided in the case study on the HSL-Zuid in a master thesis on the flexibility of a DBFM contract (Roosjen, 2013).

In the case that a SVP is put through, then an implementation process starts. While the contract extensively describes many aspects of many processes, a respondent states: “The… problem was that the lead time of the impact analysis was not specified which allowed a lengthy process.” (appendix F.9). Furthermore, another respondent states: “The DBFM contract on the HSL-Zuid left room for discussion which decreases effectiveness and efficiency.” (appendix F.6). Furthermore, some parts of the contract that are too strict for realization. All these reasons led to various discussions which decreases trust between stakeholders. This is confirmed by an extensive evaluation done by Decisio commissioned by the Ministry (Decisio, 2020). This confirms the adaptability factor for process clarity.

This also led to unacceptable risk management (Algemene Rekenkamer, 2007). Knowledge about potential risks were not adequately shared between stakeholders. This is understandable because the contract has been setup in such a way that all stakeholders want to minimize their own risks. However, this gave the Netherlands Court of Audit the conclusion that the quality of risk management was insufficient (Algemene Rekenkamer, 2007). A good cooperation with good chemistry is of utmost importance to properly manage risks (Verhees, 2013). This confirms the need for stakeholder involvement as adaptability factor.

This analysis is based on the examples mentioned in the different interviews (appendices F.6 to F.10). These examples mainly surround issues related to the adaptability of the HSL-Zuid:

- The implementation and changeability of the RBC (appendices F.7 & F.9).
  The current RBC is provided by Thales while the rest of the signalling system is provided by Siemens. This RBC is likely to require a renewal in the near future. However, the system is configured in such a way that it works with the Thales RBC and might need extensive reconfiguring if choosing for a Siemens RBC.
- The connectivity problems of the RBC (appendices F.7 to F.10).
  From 2009, connectivity problems caused trains to stop on the HSL-Zuid causing delay. In 2011 and 2012 two parameters were investigated and chosen to change for fixing the problem. It resulted in almost two years before the change was actually put through into realization phase due to steep conditions by parties and undefined lead time for the impact analysis.
- The windshields on Hollands Diep (appendices F.8 & F.10).
  Strong wind causes speed restrictions or even disruption of operation on the bridge over the Hollands Diep. This problem was known from the start. The effect was accepted. In 2010, the option to construct wind screens was considered. In 2020, the windscreens are going to be placed.
- The potential update of ERTMS (appendices F.6 & F.8).
  The current ERTMS SRS 2.3.0 Corridor is perceived as dated technology. An update towards B3 is still under discussion with restraint of Infraspeed to make this change.

5.1.2 Conclusion

The chosen contract form enforces the contractor to optimize safety and availability through KPIs in the contract. To make changes with a SVP could potentially introduce additional risks that have a negative impact on these KPIs. Due to the contract form, Infraspeed and its shareholders are averse to additional risks and thus potentially opposed to changes. Every SVP could lead to a discussion about scope, costs and delivery time. All these reasons lead to unrealizable lead times and challenges in pricing, which decreases the business case for each change. For these reasons, the chosen contract form results in a decreased adaptability.

Some changes, like the connectivity problems with the RBC, are so desirable by The State, that Infraspeed is put under pressure by escalating towards a discussion between high level directors and the Secretary of State. One can be quick in condemning Infraspeed to let it get so far. However, it is understandable from their viewpoint. This process is a consequence of a form of contract where individual risk minimization is stimulated, which result in a sub-optimal situation for the traveller and resulting in decreased adaptability.

5.2 Case study II: RouteLint

RouteLint is a driver information system (DIS) originally devised by ProRail to improve cooperation between dispatchers and train drivers. It started out as idea in 2003 to create an interface providing real-time network information from the TMS to the train driver (van Luipen, 2019). RouteLint is an application that can be installed on a range of devices which has various realized benefits. Firstly, as originally intended, it improves cooperation between dispatcher and train driver, thus increasing the insight for decisions for train drivers. Secondly, it improves energy consumption because train drivers can anticipate better on upcoming situations. Thirdly, it improves safety and punctuality because it visualises real-time delay of preceding trains. To gain insight in RouteLint and its implementation, four stakeholder interviews have been conducted:

- Program manager Innovation of ProRail (appendix F.11)
- Implementation manager RouteLint of ProRail (appendix F.12)
- Program manager RouteLint of NS (2nd phase) (appendix F.13)
- Program manager RouteLint of NS (1st phase) (appendix F.14)

5.2.1 Adaptability in the project

This case, through the interviews, focusses on the following adaptability factors: stakeholder involvement, modularity, operational compatibility and standardisation. The implementation and its required adaptability is viewed by all four respondents as a success. There are various reasons for this conclusion. The first reasons is that RouteLint has been setup as application instead of an integrated solution. A respondent states: “Data is harvested in data systems of ProRail. This data is sent as text string (about 100 characters) towards an app, which is managed by an operator.” (appendix F.11). Because the app is managed by an operator, it is free to install on a range of devices. While RouteLint is defined as application, it could be specified as real-time data source which is usable for operators to use and insert optimally in their workflow. Operators could subscribe to RouteLint and device their own application. NS, for instance, first used RouteLint on their RailPocket device. After a few years of innovation, the application required a redesign to work on the TimTim (Emerce, 2018). NS further developed the application on the TimTim to provide simple driver advice. The setup of the system allowed NS to use the data to create a DAS, emphasising the ability for continuous improvement and therefore indicating a good adaptability. If a freight or passenger operator wants to use RouteLint and they do not have the IT resources to device their own application, they can use the predesigned application which is visualised in Figure 21. This uncoupled interface strengthens adaptability due to the changeability of both the transmitting and the receiving component and the standardised data stream. This is stated as such by a respondent: “It was important for the success of RouteLint that the provided data could be handled in a flexible manner”. (Appendix F.11). Confirming the adaptability factor of modularity and standardisation.

While the structure was established in a modular fashion, it was, according to the respondents, not necessary for RouteLint to require fundamental adaptability after its introduction. The respondents mentioned two main reasons for this. The first is that RouteLint is designed in close cooperation between the innovators, end users and decision makers. The second reason is that its functionality is very simple and understandable.

This close cooperation led to a clear view of the desires and requirements of the train drivers and dispatchers. With this, an application could be made that was in line with its actual usage. A lot of effort went into this close cooperation. This confirms the adaptability factor on operational compatibility. The following actions were taken:

- Various professionally organized sessions were held which were used to explain RouteLint and to arrange that the right people met the right people.
- Ambassadors were assigned that promoted the product within their influence circle.
- PR-products were developed like a movie clip and a simulator.

The second reasons describe that the design was kept as simple as possible. With the required functionalities clear from the end users, several ergonomic designers were hired to design the application.

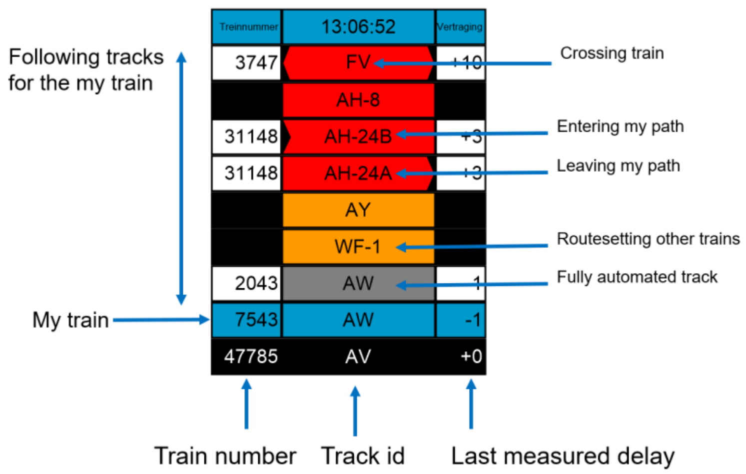

Figure 21: GUI (Graphical User Interface) by ProRail of RouteLint. Edited figure from van Luipen (2019).

RouteLint has known an innovation phase and two implementation phases. This is visualised in Figure 22. Its innovation phase was used to generate support with the end users and the decision makers with methods mentioned earlier. All these things led to great support. After this phase, an experiment was started to test RouteLint on a large scale on one corridor. During this test, the construction of the cab was altered for RouteLint and train drivers were educated for its use. However, the test showed that RouteLint did not reach the envisioned energy savings. In short, the business case was not the success hoped for and NS froze their implementation program, essentially freezing the entire program. According to the respondents, this choice to fully freeze the program instead of allowing further development had three possible underlying reasons. As one respondent states: “The financial crisis led to RouteLint being on hold." (appendix F.12), while another respondent states: "The business case was not successful which led to the stop of the project. … Another reason that the project was not continued was that another simple method was in development during the same period that increased energy efficiency as well. … It was just bad luck for RouteLint." (appendix F.14). However, due to the gathered support this choice was conceived as a great disappointment throughout the sector, including the involved NS directors themselves.

An unfortunate train accident in Amsterdam in 2012 led to the STS-improvement program (stoptonend sein). The English term is SPAD (signal passed at danger). This program showed that RouteLint increases safety, which could prevent similar accidents if implemented. The crisis led to the restarting and acceleration of the implementation of RouteLint, ultimately leading to the official launch in 2016 (van Luipen, 2019). During this second phase, it was the intention to implement RouteLint as soon as possible. A respondent states: "… one of the goals was to adopt to a minimal amount of changes to make the process manageable." (appendix F.13).

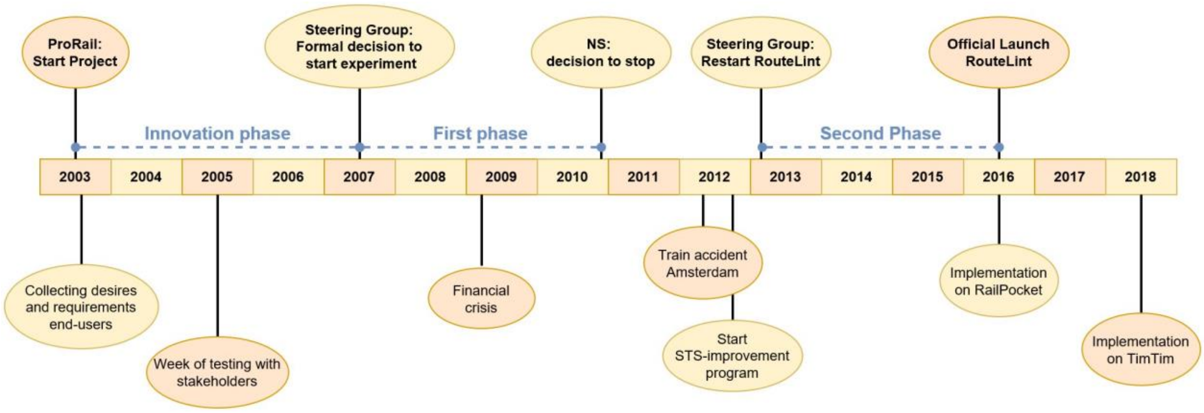

Figure 22: Timeline of the implementation of RouteLint

The description of its history makes clear that there are factors affecting the implementation time that are almost impossible to control. However, adaptation to these factors can be influenced. An argument can be made that the second phase was a success due to the alignment in the sector which was formed earlier due to the extensive effort on stakeholder management. For instance, in the second phase, various appointed ambassadors still were interested in contributing to the cause.

A respondent states: "The risk analysis required more effort than originally thought." (appendix F.13). While RouteLint is only a driver information system operating in SIL-0, it was still necessary to perform a thorough safety analysis during all three phases. It was especially difficult to prove that RouteLint was not a distraction for the train driver which could compromise safety. Furthermore, established safety cases in the first phase were not viable anymore and were redone in the second phase.

Furthermore, the updating of the application was a cumbersome process in its early days. All train drivers that used the system must go towards a certain location in order to update the system which took around 5 minutes. However, this was later upgraded by operators to an application which was updated automatically through the app-store. This was possible due to the earlier mentioned uncoupled and modular system which allows the application to be changed on a certain device without requiring the data source to change as well.

5.2.2 Conclusion

RouteLint is a successfully implemented innovation with a few identified factors that influenced the adaptability. All respondents argued that RouteLint was established in such a way that the need for adaptability was influenced. The functionality was simple and came direct from an extensive collaboration with the end users. A lot of effort was put into stakeholder management during the innovation phase. This led to very few questions on the functionalities of RouteLint increasing adaptability.

However, different designs were required for different operational needs and IT policies of operators. Due to the modular uncoupling of application and data source, it can be implemented in different devices. The string of text transmitted by ProRail is standardised and can be utilized in an application managed by the operator. This interface allows changes on both sides without disabling the use, like the facade pattern described in section 3.6.4. This increased adaptability in such a way that continuous development towards creation of a DAS on the TimTim by NS.

This interface allows the change done by operators to produce an application on the app-store instead of having a dedicated system. This change improved the efficiency of updating tremendously by removing the necessity for train drivers to go to a certain spot in order for the system to update.

5.3 Case study III: OV-Chipcard

At the end of the twentieth century, the Dutch public transport sector desired a national payment system to modernize ticketing. In 2001, five large operators established Translink Systems (TLS) that is renamed later to Translink. These five operators consisted of three regional operators GVB, HTM and RET, the bus operator Connexxion and the Dutch national train operator NS. The goal of TLS was to acquire a new system that supported all roles in the sector.

In June 2006, the Minister gave green-light for the national implementation of the OV-Chipcard (Tweede Kamer, 2006). The design of the card and its system was proposed by the consortium East-West e-ticketing B.V. which received the concession to implement the system throughout the Netherlands. It was based on the Octopus travel card which is used in Hong Kong since 1997. To gain insight in the adaptability of the project, the following employees of the stakeholders have been interviewed:

- Manager of Translink and former manager of the consortium East-West (appendix F.15)
- Former integration architect of Connexxion and business architect of TLS (appendix F.16)
- Contract manager OV-Chipcard of NS (appendix F.17)
- Business Innovator of Translink (appendix F.18)

5.3.1 Adaptability in the project

This case, through the interviews, focusses on the following adaptability factors: flexibility management, leadership, standardisation and stakeholder involvement. TLS had specified its request as “multi-vendor” to the market. A respondent states: “By specifying the request as “multi-vendor”, Translink made sure that the technical solution provided by the consortium would be open in such a way that suppliers could connect to the constructed system after its realization.” (appendix F.15). Any supplier that bid on the concession had to demonstrate that its proposed payment system was working. Only if this demonstration was a success, then corresponding liabilities were conveyed to

TLS. This setup was researched extensively to make the OV-Chipcard adaptable towards the future and neutralize the possibility of a vendor lock-in. The supplier that won the concession was, as mentioned, the East West e-ticketing B.V. consortium. While the choice for this multi-vendor construct is seen as effective, it had its drawbacks. One respondent states that this type of request: "… resulted in a higher summed amount of development costs for Dutch operators." (Appendix F.18). Each individual supplier had to develop a system based on this open architecture which introduced development costs and corresponding lead times. However, otherwise the construct could create a vendor lock-in with corresponding other issues. With this open architecture, a standard was introduced that allowed the generic OV-Chipcard to be read by different systems throughout the public transport sector. This confirms the adaptability factor on standardisation.

The implementation of the new payment system started with a pilot in Rotterdam. During this pilot, various issues arose that were not a problem in Hong Kong, but were different in the Netherlands. As one respondent states: "The small pilot in Rotterdam allowed detection and fixing of early issues." (appendix F.18). Examples are the cumbersome process of acquiring an OV-Chipcard and the branding of the cards by each operator. Furthermore, unmet requirements surrounding the security of the card resulting in privacy concerns, which is not uncommon with smart travel cards (Pelletier et al., 2011). This issue was fixed by replacing the chip in all distributed cards, which was a cumbersome intervention. The impact of these issues were limited due to the fact that these were detected during the pilot phase in Rotterdam instead of during the nation-wide implementation. Confirming the adaptability factor on flexibility management.

TLS was established by five operators to acquire a national payment system. Most of the investment for this project came from a large fund named, FENS (Fonds Eenmalige bijdrage Nederlandse Spoorwegen, Fund Single Contribution Dutch Railways), that was allocated to ProRail and NS by The State for their sold telecom shares. With this investment and their position as large operator, NS became heavily represented as shareholder acquiring 68.75% of the shares in 2008 (ACM, 2013). Other parties had less shares: GVB (12,5%), RET (12,5%) and HTM (6.25%). Connexxion was no longer shareholder from 2008. The authority consumer & market (2013) conclude that NS had a strategic advantage as consequence to their large share in TLS. This allowed NS to prioritise issues that had an impact on their company. A respondent states: "Other parties could not continue the implementation without NS as largest operator." (appendix F.17). This situation led to distrust between stakeholders and the idea that operators were treated unequally by TLS and The State. This is confirmed by an analysis on this governance structure (Veeneman et al., 2011). Veeneman et al. (2011) suggest that The State could serve as harmonizing factor between shareholders. However, they held off involvement. This confirms the adaptability factor on leadership gathered in the literature review. While the stakeholders did implement the OV-Chipcard together, they did not fix the issue of transferring between operators and its requirement for travellers to check-in and out for each operator change. This kind of transfer is considered stressful and leads to costly mistakes for travellers and decrease of trust in the system (Joppien et al., 2013). The State, as central leader, could have stimulated focus on the traveller. This confirms the adaptability factor on leadership.

5.3.2 Conclusion

The implementation of the OV-Chipcard had various factors influencing adaptability. Due to the "multi-vendor" request, an open architecture was established for the system that served as standard for other suppliers to connect with neutralizing vendor lock-in. Confirming the standardisation adaptability factor. Because the implementation started small as pilot in Rotterdam, various issues related to the Dutch implementation of a smart travel card could be detected and fixed without the necessity to change nation-wide implemented components. Confirming the adaptability factor on flexibility management. Because NS was large shareholder of TLS and nation-wide operator, they had a large interest and influence on the process of implementation. This led to distrust between stakeholders and the idea that operators were treated unequally. The State could have served as harmonizing factor. Confirming the adaptability factor on leadership and stakeholder involvement.

5.4 Adaptability factors

The case studies are performed using the questions formulated in section 2.5 as guidance. Each case study uses real-world examples to give insight in how these adaptability factors work in practice. Table 16 describes various deducted methods gathered in the case studies as confirmation to the factors in section 2.5 or as additional information on how various methods can influence adaptability. Furthermore, the methods are merged based on their common ground in various factors. These factors are then used as base for formulating proposed solutions in chapter 6. All adaptability factors identified throughout this thesis are described in section 6.1.

Table 13: Adaptability factors that are confirmed in the case studies which are identified the literature review. These factors are provided in the form of one or multiple methods.

Factor	**Method description**
Flexibility management	When a technological developing project is tendered, make sure that changeability is rewarded instead of indirectly penalized (section 5.1).
	Start implementation in a small area or region to allow an increased ability to detect and fix early issues (section 5.3)
Stakeholder involvement	Chemistry and cooperation between stakeholders must have a focus throughout the project to make sure that an aligned solution is found for arising problems and that the necessity for changeability is decreased. A stimulating factor is setting aligned goals using joint KPIs (sections 5.1 & 5.2).
	Potential risks must be shared between stakeholders for increased risk management (section 5.1).
	Having support on an innovation in the sector is stimulating the ability to deal with arising issues. This can be achieved by appointing ambassadors, organized meetings and a range of PR-products (section 5.2).
Operational compatibility	Involve end users and decision-makers early in the process to make sure that operational desires and requirements match the product implementation (section 5.2).
Process clarity	Make sure that, if the contract is extensive and strict, every process and its boundaries such as specified lead times, are well defined (section 5.1).
Modularity	Form a facade between components to establish modularity such that these are changeable if requirements change or the lifespan ends (section 5.2).
Standardisation	Standardize interfaces to improve the adaptability between components (sections 5.2 & 5.3).
Leadership	Without a central leader that ensures integrity and purpose, the largest shareholder could become the majority shareholder that allows significant influence over the chosen direction leading to distrust. (section 5.3)

6. ERTMS adaptability analysis

This chapter provides proposed solutions that could improve the adaptability of the ERTMS implementation. These solutions are based upon the analyses in the previous chapters that identified adaptability factors and critical issues. The solutions are categorized to match a specific topic. Section 6.1 starts with a description of the identified adaptability factors and provide information about their interrelation and stakeholders that can influence these. Section 6.2 provides the solutions to improve the technical adaptability. The solutions that improve adaptability with respect to the governance and stakeholder management are described in section 6.3. The last category, in section 6.4, describes the proposed solutions on financial and regulatory adaptations which improve adaptability. Each section starts with a generalised statement on improving adaptability that corresponds to the section. The proposed solutions are validated by three experts in a use case in chapter 7.

6.1 Adaptability factors

The performed analyses identified various factors that influence adaptability. These factors are summarised in Table 14. The literature study provides a list of adaptability factors in section 2.5. The analyses of the ERTMS basics and its future developments provides two lists of critical issues where the adaptability of the Dutch ERTMS implementation can be strengthened in sections 3.7 and 4.5. The case studies provided adaptability factors in section 5.4. These formulated factors are integrated and translated into the various proposed solutions listed in this chapter.

Table 14: Summarised factors that influence adaptability (sections 2.5, 3.7, 4.5 and 5.4).

Factor	Description
Stakeholder involvement	The involvement of various different stakeholders increases sector-wide support for decisions thus decreases the need for adaptability.
Process clarity	Improving the clarity in the implementation process by providing information for preparation of stakeholders through road mapping or a simulator.
Leadership	Strong leadership ensures integrity and purpose in the process.
Flexibility management	Preserve the ability to change direction with respect to technology and governance.
Modularity	The ability to replace or implement components without requiring to modify existing components.
Standardisation	For interoperability, ensure standardisation in interfaces and components.
Operational compatibility	A technological implementation might also have an effect on operational aspects.
Technology updating	Necessary technological changes after implementation of components that contain errors.
Future needs	Requirements due to upcoming innovations.

Logically, these factors have relations between them. There is tension between stakeholder involvement and leadership. If stakeholders are heavily involved, strong leadership may not be accepted and vice versa. There also tension between process clarity and flexibility management. A respondent states: “Transparency about expected change could result in restraint of parties to update or upgrade today.” (Appendix F.21). Furthermore, a positive relation exists between standardisation and modularity. These two factors are strongly linked as described in section 3.6.4.

6.2 Technological implementation

This section provides the proposed solutions for improving adaptability of the planned Dutch ERTMS implementation from a technical viewpoint. It starts with solutions on ERTMS baseline and ETCS application level management after which the solutions are given on adaptability towards future innovations by describing interface and component management. The solutions are validated by three experts in a use case in chapter 7.

6.2.1 ERTMS baseline management

Multiple sections in this thesis describe the importance of the conditions surrounding standardisation of a system. The literature study showed that standardisation can provide a beneficial environment for adaptability if a single and well-designed standard is dominant which does not leave room for interpretation . This is confirmed by the case studies on the implementation of the OV-Chipcard and RouteLint which, by using a well-designed and dominant standard, allowed the public transport sector to connect to these systems more easily.

In the ERTMS implementation, this translates to the importance of baseline management. The analysis of ERTMS endorses the necessity to have a transparent and well-planned baseline management. This can be further stimulated by transparent stakeholder involvement with a comprehensive roadmap to provide clarity as discussed in section 6.3.2. Tendering small regions stimulates insertion of changeability in the contract as stated in section 6.3.4. This is translated into various solutions that are shown in Table 15.

Table 15: Proposed solutions on ERTMS baseline management for improving adaptability of the ERTMS implementation

Factor	***Critical issue***	**Proposed solution**
Standardisation	*ERTMS baselines are not fully compatible between trackside and trainside*	Choose B3R2 as dominant standard for the currently planned trackside implementation of the ERTMS program.
future needs & process clarity	*Development in ERTMS baselines is ongoing*	Only update towards or implement with a new TSI on the infrastructure if this release is considered mature enough and when total backwards compatibility is ensured.
Technology updating & flexibility management	*An update could prove technological immature and require expensive technological changes*	If another TSI is chosen, tender a small region for implementation and use this as exercise of team learning.
Stakeholder involvement	*Stakeholders could be ill-prepared for an ERTMS baseline update*	Transparency in baseline management is vital for stakeholders (see section 6.3.2)

The reasoning behind these solutions is that it would be economically unfeasible for equipment owners, especially freight operators, if the infrastructure is periodically updated towards newer TSI's that are not backwards compatible. For example, the fact that the Betuweroute, which is implemented with B2, required freight operators to upgrade to B2 and that the current implementation based on B3 requires freight operators to retro-fit their rolling stock again is not desirable for a third time. However, it may be beneficial or even necessary to upgrade towards a new TSI for utilization of new required technology, such as FRMCS. It is vital to be transparent in the decision process for such an update.

6.2.2 ETCS application level management

As with ERTMS baseline management, the chosen application level is an important factor for the adaptability of the system. The reasons behind standardisation as mentioned in the previous section are also applicable for this kind of management. While a change in application level is relatively easier than a change in TSI, it is still important to properly manage so that stakeholders can anticipate better on different scenarios. The following solutions are formed (Table 16).

Table 16: Solutions on ETCS application level management for improving adaptability of the ERTMS implementation

Factor	***Critical issue***	**Proposed solution**
Standardisation & process clarity	*An ETCS application level change requires preparation time for stakeholders because of component requirements*	For the sake of transparency, communication about the planned application level is important. Especially because, with ETCS HL3 or L3, train-based train integrity becomes more desirable or even required.
Stakeholder involvement	*ETCS HL3 is an innovation mainly formulated and supported by IMs*	Let ETCS HL3 be a sector-wide driven innovation with adequately risk management by involving stakeholders in this process and adding it to the official ERTMS TSI

The reasoning behind these solutions is that current formal communication surrounding the ERTMS program is suggesting that ETCS L2 is being implemented with preparation towards ETCS L3. However, this is not entirely the case as suggested by some respondents, the tender of the CSS and by closer inspection of the ERTMS program decision. These indicate that, while indeed ETCS L2 is being implemented, the planned ERTMS implementation has a strong tendency for a future upgrade towards ETCS Hybrid Level 3, not ETCS L3 as currently specified in the official TSI. While the difference between ETCS HL3 and L3 can seem small, it has various effects on operation and performance (sections 3.4.4 and 4.2.1). For this reason, it is important to involve stakeholders in this decision process using solutions given in section 6.3.2.

6.2.3 Interface management

A large part of adaptability can be described as the ability to interface an existing component to an additional or replacement component without the necessity to make structural changes to the system. The literature study showed that standardisation, as mentioned earlier, is very important for this. However, the structure should be built in a modular fashion so that new components and their interfaces can be added or removed without requiring the existing components to be modified. This approach improves the preservation of flexibility, which is also noted as factor to adaptability. This is confirmed in the case studies by the technological structure enabling modularity used by RouteLint and the standardisation used in the multi-vendor request by Translink.

In the case of ERTMS, this translates to the manner on how existing components are prepared for a future interface with new components. If these components enable such an interface without requiring a structural modification after implementation of the innovation, the planned ERTMS implementation would be more adaptable. The proposed solutions are listed in Table 17.

Table 17: Solutions on interface management for improving adaptability of the ERTMS implementation

Factor	Critical issue	Proposed solution
Flexibility management, standardisation & modularity	*ERTMS and its interfaces are continuously evolving with changing needs and possibilities.*	The interface that connects existing and new components must be setup in a modular fashion using standardisation and facade patterns. The following solutions provides interfaces for which this is important with respect to the upcoming innovations in the Dutch ERTMS implementation.
Future needs & standardisation	*A C-DAS requires data from the TMS*	The (new) TMS must be prepared for an interface with a C-DAS or ATO trackside component.
	The FRMCS network must be interfaced to the RBC	The RBC must be prepared for an interface allowing bi-directional messages through the FRMCS network.
	The FRMCS network must be interfaced to the EVC/Euroradio	The Euroradio must be prepared for an interface allowing bi-directional messages through the FRMCS network with use of a FRMCS gateway.
	ATO or C-DAS on-board equipment requires data from the EVC	The EVC must be prepared to provide output through interfaces to components such as the ATO or C-DAS on-board.
Future needs, modularity & standardisation	*Virtual Coupling requires additional functionalities of the EVC*	The EVC must be prepared for an integration of functionalities needed for Virtual Coupling, such as the transmission bi-directional messages to other trains through the additional antenna and the establishment of an enhanced MA.

As mentioned, the preparation must enable interfacing in a modular fashion using standardisation and facade patterns (for further explanation see section 3.6.4). This allows better modification of the system without the necessity to modify existing components. To ensure this, it is important to have close cooperation with various experts such as those involved in European programs and initiatives such as Shift2Rail, EULYNX, RCA and OCORA. As described in the section on stakeholder involvement (section 6.3.2) it is important to involve experts and interest groups with key design decisions. Furthermore, modularity could be stimulated if changeability is rewarded instead of penalized as mentioned in the solutions in section 6.3.4. The solutions are inserted as notes into a conceptual model that positions each solution to its corresponding component or interface. This conceptual model can be seen in Figure 23.

6.2.4 Component management

Besides the ability to establish a modular interface that combines existing and new components, it is important to know overlap and synergies between these components. If a future innovation could cause the obsolescence of other innovations it could result in capital destruction. This must be taken into account of implementation and innovation plans to ensure an efficient process. For this reason, it is important to know what are upcoming innovations and their effects. This can be done by involving experts and interest groups in the process as described in section 6.3.2. Furthermore, the effects can be identified by acquiring a simulator that tests technological and operational choices.

In the case of ERTMS, the overlap and effect of innovations are analysed and modelled in section 4.3. From this analysis, a list of proposed solutions can be formulated for the planned ERTMS implementation to be future-proof and efficiently implemented. Various future innovations should be implemented in such a way that it integrates more easily in the current implementation and innovation plans. The list start with two proposed general solutions that form the foundation of the other given solutions (Table 18).

Table 18: Solutions on component management for improving adaptability of the ERTMS implementation

Factor	Critical issue	Proposed solution
Technology updating, future needs & process clarity	*Upcoming innovations could have unintentional and undesirable side effects*	Construct a simulator that could test the effect of technological and operational design choices to check if any unintentional or undesirable side effects occur. This simulator should be transparent and accessible for stakeholders.
Stakeholder involvement, process clarity & future needs	*Future developments and their effect on the current implementation of ERTMS are opaque.*	Closely follow European programs and initiatives such as Shift2Rail, EULYNX, RCA and OCORA to deduct needs for adaptability in the future. The following solutions provide information for which this is important with respect to the upcoming innovations in the Dutch ERTMS implementation.
Future needs	*ATO GoA 2 can be described as functional upgrade of a C-DAS.*	A C-DAS should be used as technological stepping stone or bridge towards the implementation of ATO GoA 2 and not serve as final product.
	Support for GSM-R is ending in 2030.	If more network bandwidth is required for the utilization of new innovations, choose for innovating towards FRMCS instead of enhancing the GSM-R network.
Future needs & flexibility management	*ETCS HL3 requires additional functionalities from the RBC*	Make sure that the CSS, the IXL and RBC combi-system, can be converted to operate under ETCS HL3.
Future needs & standardisation	*Various upcoming innovations utilize the DMI for visualizations*	The DMI must be prepared to visualize additional information from implemented innovations through standardised interfaces.
Future needs, standardisation & modularity	*Various upcoming innovations require the implementation of additional components in the rolling stock*	Construct the on-board in such a way that it allows the implementation of additional components and the connection to the existing equipment. Examples of these components are the additional antenna for Virtual Coupling, an ATO or C-DAS on-board or a dedicated HMI.

The reasoning behind these solutions is that adaptability can be strengthened if the current plans are adapted to match a preparation towards upcoming innovations. These solutions are integrated into a conceptual model that positioned each solution to its corresponding component or interface. This conceptual model can be seen in Figure 23.

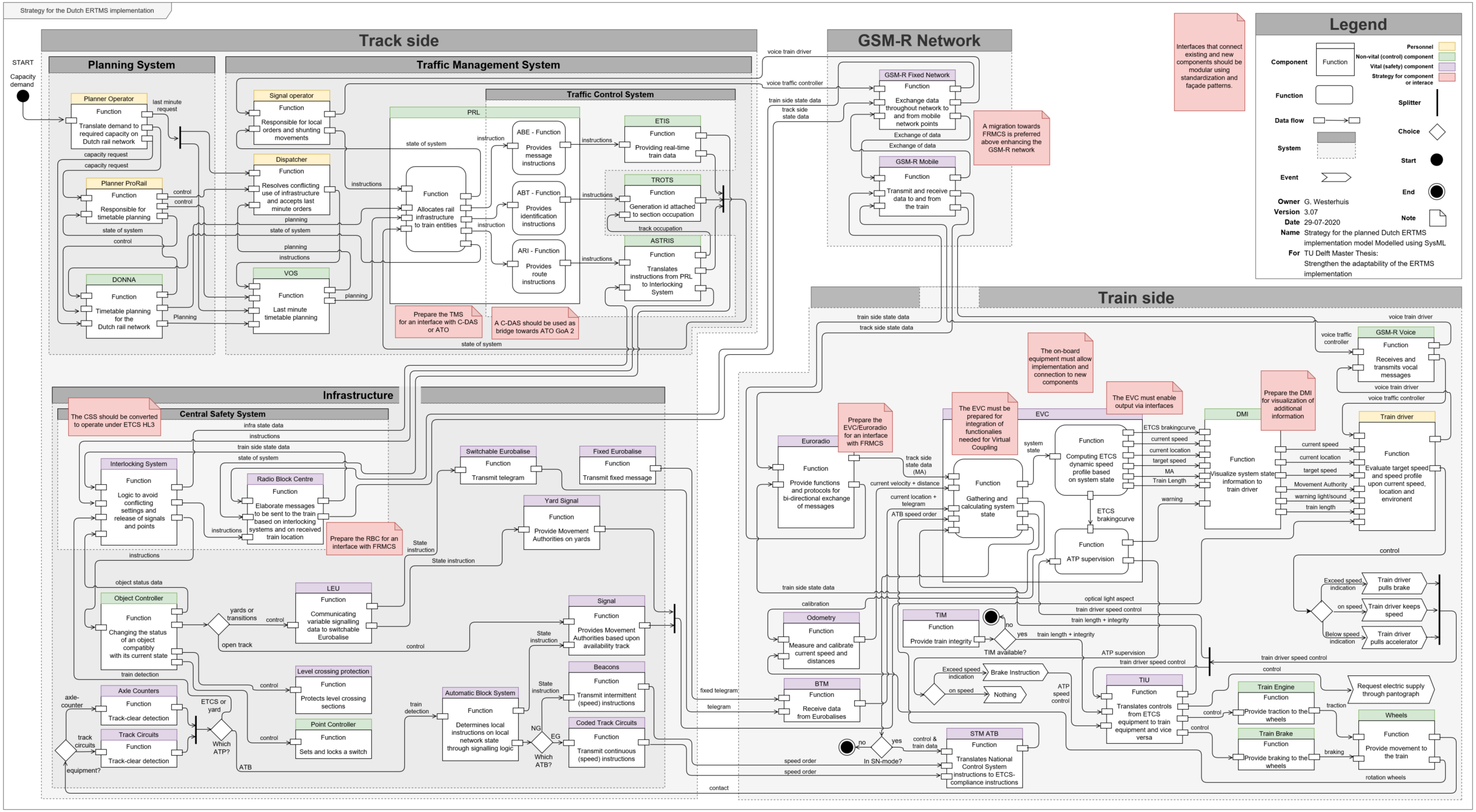

Figure 23: The strategy integrated using summarised notes in the planned Dutch implementation of ERTMS

6.3 Governance and stakeholder management

This section will provide proposed solutions for improving adaptability of the planned Dutch ERTMS implementation from a governance and stakeholder management viewpoint. The section starts with the position of the Dutch ERTMS program. Thereafter a list of solutions is given on how to involve stakeholders in order to align the sector in the implementation and on generation of support. In the final section, additional solutions are provided to improve changeability in the contract. The solutions are validated by three experts in a use case in chapter 7.

6.3.1 Position program ERTMS

The literature study shows that a strong and central leader ensures integrity and purpose if the leader is recognised and the leader recognizes the various interests of the stakeholders. This factor positively influences adaptability. This is confirmed by the case study on the OV-Chipcard where one shareholder had a large impact on the process but was not recognised as such by other shareholders. This structure led to delay and friction in the decision-making (section 5.3). The factors from the researched case studies and their used governance model in chapter 5 led to questions about the position of the ERTMS program and its corresponding governance. As described in section 3.5.1, the Dutch ERTMS program is positioned at ProRail, the infrastructure manager of the Netherlands. Because ProRail is a heavily involved stakeholder with a clear interest, it could happen that the ERTMS program, due to its positioning, acts motivated by the interests of ProRail, as agent, instead of the Ministry, as principle. This mechanism is called the Principle-Agent theory (Zhang et al., 2015). This theory argues that a principle-agent structure could increase moral risks. To what extent the mentioned factors and this theory is applicable to the ERTMS program has been validated in two interviews:

- Manager stakeholder management of NS (appendix F.19)
- The former ERTMS program manager of the Min I&W (appendix F.20)

According to these respondents, the program is somewhat sensitive for the interests of ProRail. This is due to, as one respondent states: "… an information dissymmetry. ProRail has much more knowledge about the ERTMS than Min I&W. In this instance, Min I&W must make decisions on the information given by ProRail." (appendix F.20). Furthermore, another respondent states: "It is argued that the program is a sector-driven process. However, most of its employees are from ProRail." (appendix F.19). Both statements could lead to the increasing chance that design choices are communicated between knowledgeable employees of ProRail departments and the ERTMS program instead of following the established formal routes. Examples of this sensitivity could be decisions like the potential inclusion of northern lines in the ERTMS program and the envisioned upgrade towards ETCS HL3 which allows ProRail to decrease trackside equipment (section 4.2.1)(Min I&W, 2020; SpoorPro, 2020). The following proposed solutions are formulated (Table 19).

Table 19: Solutions on the position of the ERTMS program for improving adaptability of the ERTMS implementation

Factor	*Critical issue*	Proposed solution
Stakeholder involvement & leadership	*The program is sensitive for the interests of a single or a selection of stakeholders*	Stimulate the diversity in viewpoints, backgrounds and expertise in the ERTMS program by mixing its employees that origin from various stakeholders such as RUs, IM and Min I&W.
		Form central and strong leadership in the program by establishing the environment where the program manager of Min I&W has the technological knowledge and resources to function as a capable counterpart to the program management team.

The reasoning behind these two solutions is based on the researched factors which are tailored to the ERTMS program combined with the input from the two respondents. As one respondent states: "It amazes me that the Ministry did not have questions about the percentage of ProRail employees on the program ERTMS." (appendix F.19). The other respondent states: "The task for Min I&W is to guard that the program ERTMS stays independent and that no through passage is made between different departments of ProRail and the program." (appendix F.20). Both solutions are aimed to improve the balance of different stakeholder interests in the ERTMS program and thus decreases the effect of the principle-agent problem. This balance could improve the technical adaptability towards new innovations as described in sections 6.2.3 and 6.2.4. It is important to note that strong leadership introduces tension with measures for stakeholder involvement described in 6.3.2 and vice versa. Therefore, parties should aim to find a good balance between the two that is appropriate per situation.

6.3.2 Stakeholder involvement

Various formulated factors in the literature study show that involvement of stakeholders is of utmost importance to increase adaptability. Factors on process clarity state that a frequent and transparent update on status and planning with the possibility of comprehensive feedback allows decision-making and solution-finding from a sector-wide perspective. From the case study of RouteLint can be identified that frequent involvement of stakeholders decreases the need for adaptability because decisions are made by the sector itself (section 5.2).

In case of the ERTMS implementation, this is endorsed by various factors. The proposed solutions listed in Table 20 have the goal to increase cooperation and coordination in order to increase the ability to be adaptable while, at the same time, this decreases the need for adaptability. It is important to note that stakeholder involvement introduces tension with measures for strong leadership described in 6.3.2 and vice versa. Therefore, parties should aim to find a good balance between the two that is appropriate per situation.

Table 20: Solutions on the involvement of stakeholders for improving adaptability of the ERTMS implementation

Factor	***Critical issue***	**Proposed solution**
Stakeholder involvement	*Coordination between stakeholders*	Stimulate that employees of different stakeholders interact in an informal manner on a frequent basis.
Stakeholder involvement & flexibility management	*Cooperation between stakeholders*	Stimulate cooperation and coordination by introducing joint KPIs for the IM, freight and passenger operators.
Stakeholder involvement & flexibility management	*Coordination and sector-wide support at key decisions*	Plan organized meetings for stakeholders when key design decisions are made to ensure transparency, a more sector-wide supported decision and improved handling of uncertainty by explicitly sharing of perceived risks.
Operational compatibility & stakeholder involvement	*Focus on operational aspects of the ERTMS implementation*	Involve end users, such as train drivers and signal operators, to minimize the need for adaptability by increasing focus on operational aspects.
Stakeholder involvement, future needs & process clarity	*Future developments and their effect on the current implementation of ERTMS are opaque.*	Involve experts and interest groups when key design decisions are made to ensure a more future-proof direction
	Provide sufficient preparation time for stakeholders	Introduce a comprehensive roadmap to provide information on planning, status and key design decisions, such as innovations, to stakeholders.

The reasoning behind these solutions is that cooperation and coordination is important in a complex system integration process with a range of different responsibilities and interests, such as the implementation of ERTMS. The provided solutions stimulate that potential benefits and costs of the ERTMS implementation are more equally and fairly distributed between the stakeholders while preserving agreement and support. Furthermore, when stakeholders are involved, technical risks could be shared better improving the likelihood of a successful implementation as described in sections 6.2.3 and 6.2.4. While the solution is chosen by the Dutch program ERTMS in cooperation with its steering group, the potential solution options should be composed by the sector itself through stakeholder involvement.

6.3.3 Generation of support

Besides involvement, it is important to have support for the implementation in multiple working layers of the involved stakeholder companies. This is substantiated by the case study on RouteLint (section 5.2). This case showed that having support decreases the negative effect that problems could have on the implementation process and increases the adaptability due to the willingness in the sector.

ERTMS has many components, each with its own development and different processes. The implementation of ERTMS would be more adaptable if the employees working on each component would be better interconnected so that knowledge can be more easily shared thus stimulating a sector-wide optimum instead of a local optimum. In this way technical aspects of innovations that lie with different stakeholders can be shared to compose a supported implementation approach. Furthermore, as described, support decreases the need for adaptability due to alignment in the sector. The proposed solutions are provided in Table 21.

Table 21: Solutions for generation of support to improve adaptability of the ERTMS implementation

Factor	***Critical issue***	**Proposed solution**
Stakeholder involvement	*Interconnection between stakeholders and support of ERTMS and upcoming innovations*	Form a network of ERTMS ambassadors at different stakeholders to increase the support of the implementation and to increase the connectivity and findability of the various experts in the field.
		Plan organized meetings to explain the current functionalities and potential future possibilities of ERTMS to stakeholders.
		Design visualizations such as infographics or movie clips of the current functionalities and potential future possibilities of ERTMS for stakeholders.

6.3.4 Changeability in the contract

The case studies in chapter 5 show that contractual factors can hinder or stimulate adaptability. The HSL-Zuid case can be taken as example where availability and safety was enforces by the contract which, in this case, decreased the ability to implement changes (section 5.1). For this reason, the project was not considered very adaptable. The lesson which can be learned is that adaptability should be rewarded instead of penalized. The OV-Chipcard case showed that an implementation can start in a specific region as pilot before other regions are added to the implementation process (section 5.3). This methodology allowed to detect and fix issues between regions instead of requesting modifications during implementation or afterwards for larger regions or even the entire nation. This proved to increase adaptability of the implementation. Both factors are endorsed by factors on flexibility management from the literature study that argues for the preservation of technological and organisational flexibility in the project (section 2.5).

These factors can be translated into proposed solutions for the implementation of ERTMS. Both case studies are somewhat identically applicable due to the similarity of the specific conditions in both cases. For the HSL-Zuid because it was also an instance of ERTMS implementation. For the implementation of the OV-Chipcard due to its identical implementation area: the Netherlands. The proposed solutions that are formulated with these factors are given in Table 22. These solutions provide means to implement potentially necessary innovations, such as the upcoming FRMCS, into the system with a less hindering contractual structure.

Table 22: Solutions for changeability in the contract to improve adaptability of the ERTMS implementation

Factor	***Critical issue***	**Proposed solution**
Flexibility management	*Changeability could be decreased due to the setup of the contract.*	During the implementation phase and the potential maintenance phase, make sure that changeability is rewarded instead of penalized.
	Static policies for a continuously evolving system	Preserve the ability to change corresponding policies so that these could be adapted if these do not suffice.

6.4 Financial and regulatory adaptations

This section provides the formulated solutions that correspond to financial and regulatory adaptations. First, the importance of available budget is discussed. After which the necessity for a changed certification and acceptance approach is described. The solutions are validated by three experts in a use case in chapter 7.

6.4.1 Availability of budget

Based on the factor on technology updating, the critical issue relates to that marginal technological changes are conceived as expensive. In sections 3.6.2 and 4.4.3 the importance of available budget as proposed solution for this issue is described. This issue is repeated multiple times by the EC as factor that decreases adaptability. However, marginal technological changes might be necessary in order to fix an otherwise unexpectedly dysfunctional system. This is endorsed by the HSL-Zuid case in section 5.1.

6.4.2 Certification and acceptance

Based on the factor on flexibility management, the critical issue is that changing national values result in the necessity to entirely recertify vehicles. The proposed solution is to certify on-board equipment against various applicable ranges of national values instead of certifying it only to the currently used national values (section 4.4.2). If the latter approach is chosen, then a vehicle must be recertified fully in various countries if one country changes its national value as explained further in section 4.4.2.

7. Use case

In order to test and validate the effect of the proposed solutions from chapter 6, a use case is established. This use case is based on a corridor which was constructed using the ERTMS implementation adapted according to the proposed solutions. On this corridor with its corresponding environment, a metaphorical development is simulated based on a probable scenario. This corridor and its development is described in section 7.1. In this use case, the effects of this development and the inability for the system to adapt, are identified and thus the effect of the proposed solutions are assessed. The effects are categorized in technical implications (7.2), implications for governance and stakeholder management (7.3) and financial and regulatory implications (7.4). Three experts are consulted to criticize or endorse the proposed solutions in the context of this use case. The following experts are consulted:

1. Program manager ERTMS of the Min I&W (appendix F.21)
2. Legal Advisor of the Min I&W (appendix F.22)
3. ERTMS expert of Ricardo (appendix F.23)

7.1 The chosen scenario

The chosen corridor is Kijfhoek – Roosendaal. A corridor that is used by both freight and passenger operators. According to the recent progress report by the Ministry, this corridor will be equipped with ERTMS only with B3R2 operating under ETCS L2 between 2026 and 2028 (Min I&W, 2020). After implementation, commercial use starts directly. While GSM-R is originally implemented, the Dutch program ERTMS desires a migration towards FRMCS-only on this corridor. However, in order for FRMCS to be implemented, the infrastructure on this corridor must be upgraded towards the next set of specifications (TSI) which is assumed in this use case to be entirely backwards compatible to B3R2 track and trainside with respect to other aspects of ETCS. However, the migration to FRMCS requires a dual mode to be implemented in the train which allows operation under GSM-R and FRMCS. It is assumed that this dual mode requires a change in the Euroradio as described in section 4.2.3 and visualized in Figure 15. The aspects of the scenario are visualized in Figure 24.

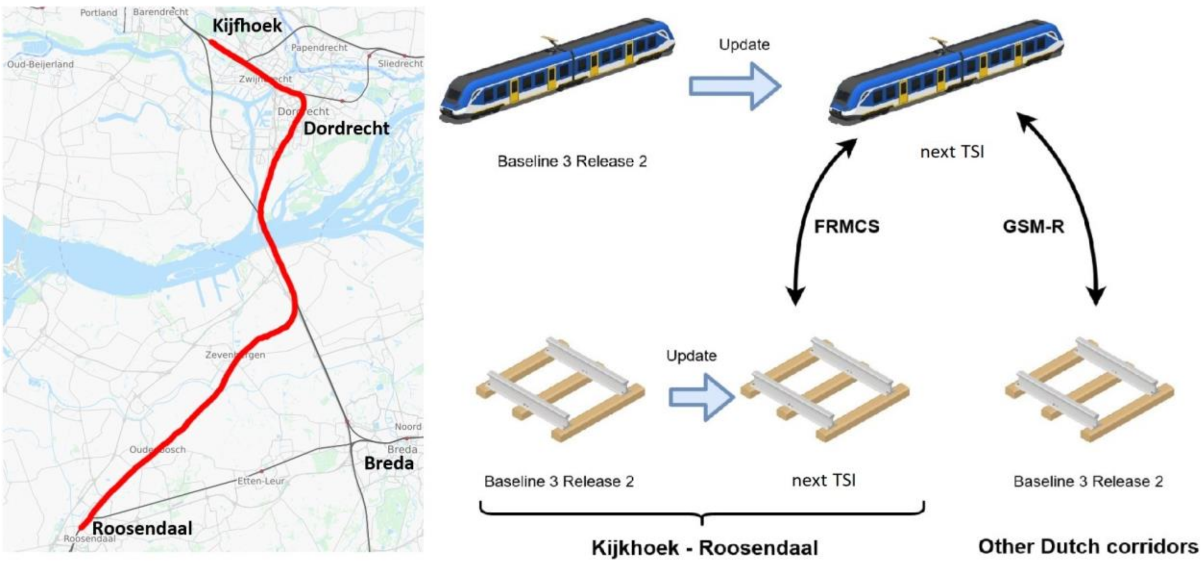

Figure 24: The chosen scenario for the use case
Left: Corridor Kijfhoek – Roosendaal edited. Right: scenario of the FRMCS migration and update of TSI

In summary, the aspects of the chosen scenario are as follows:

- The chosen corridor is Kijfhoek – Roosendaal.
- This corridor is used by freight and passenger operators.
- The trackside is updated from B3R2 towards the next set of TSI.
- The FRMCS-only network is implemented in phases on this corridor.
- On-board equipment is required to update from B3R2 towards the next set of TSI.
- On-board equipment requires a dual mode that allows operation under GSM-R and FRMCS.

In the following sections, the various implications for the Dutch ERTMS implementation, amended with the proposed solutions, are described.

7.2 Implications for technical aspects

If ERTMS is implemented according to the amended Dutch ERTMS implementation, then no issues would arise in the use case on migrating towards a new TSI and FRMCS-only on the corridor Kijfhoek – Roosendaal. This is endorsed by the interviewed ERTMS expert (appendix F.23). However, according to this respondent there are some feasibility issues on the proposed solutions.

The main shortcoming of the proposed solutions is, as one respondent states: “New innovations cannot be applied in rolling stock if official specifications are not released.” (appendix F.23). In the case, there is restraint of the ETCS industry to sell components that are prepared for FRMCS, before the actual inclusion of the FRMCS standard in the official TSI. The signalling industry requires to see official specifications. Draft documents are considered insufficient. In the use case, this means that no preparation of the Euroradio to FRMCS can be requested before its expected inclusion in the next TSI.

The main endorsement of the proposed solutions is the necessity of modularity of the system. If the on-board equipment is established in a modular fashion, a FRMCS module could be tendered individually. If it was not established in a modular fashion, the entire ETCS equipment, including the FRMCS components, must be tendered. Modularity increases adaptability and would decrease the price for a component as a respondent states: “Modularity is a mean to increase financial lifespan of on-board ERTMS and decrease price for upgrades of ERTMS. Components should be uncoupled according to their market feasibility.” (appendix F.23). Thus, if the system is modular, the lifespan of other components would increase due to the ability to only replace the component with the shortest lifespan.

One further comment that is made on the solutions and that is their dependency on time. While the solutions are endorsed by the expert in the current situation, in the light of the use case, conditions could be different in a few years. Innovations could be further developed or changed, which determines the maturity of new technology and TSIs

7.3 Implications for governance and stakeholder management

Governance and stakeholder management has a diverse range of aspects that were difficult to capture in one use case. While this case introduced various changes affecting various stakeholders, the use case should be viewed besides the entire ERTMS implementation program. Furthermore, the effects of the aspects and solutions that relate to governance and stakeholder management are difficult to assess. These implications are mostly validated by the ERTMS program manager of the Min I&W (appendix F.21) and the legal advisor of the Min I&W (appendix F.22).

The main shortcoming of the proposed solutions is the absence of the use of the entire range of instruments available to provide a good governance and stakeholder management. The current solutions have a strong focus on involvement and transparency, which are endorsed by the respondents. However, the use of non-binding measures only could prove ineffective as one respondent states: “Policy cannot be written only on informal interaction.” (appendix F.21). Only the use of instruments that stimulate involvement and transparency could result in, as one respondent states: “restraint of parties to update or upgrade today” (appendix F.21). In the use case, that would mean that operators are reluctant to implement GSM-R with the knowledge that a migration to FRMCS is planned in the near future. A respondent suggests: “The proper and firm use of all instruments is necessary, not only with non-binding measures. … Examples of these instruments are regulations, obligations, agreements, subsidies and communication.” (appendix F.22).

The main endorsement, by all three respondents, is the creation of a comprehensive roadmap that informs stakeholders on when which corridors are addressed with what measure. As a respondent state: “A roadmap must be established where innovations are put into time periods enabling the ability for parties to prepare and anticipate.” (appendix F.21). However, it is important to provide enough legal certainty so that parties can depend on it. Otherwise, as one respondent states: “Stakeholders would send financial claims for damages based on the general principles of good administration.” (appendix F.22). These claims are caused by unexpected deviations resulting in unused or non-operational equipment.

Furthermore, two main comments were made on the solutions. The first is that, while it is supported by the experts that the program manager of the Min I&W should be able to perform checks and balances as strong and central leader, it is mentioned that not only this role should be supported. A respondent states: “Not only the program manager of Min I&W must have the position to fulfil its role. All roles must function in compliance with the intended governance model.” (appendix F.22). The second comment is focus on the introduction of the joint KPIs. While its functionality is endorsed, it is of vital importance to create a well-designed KPI. As one respondent states: “… joint KPIs… could also have the negative side effect of parties having restraint to innovation due to the risk of unmet standards.” Such measures could have negative side effects as shown in the case study on the HSL-Zuid (Section 5.1).

7.4 Implications for financial and regulatory aspects

While the solution on certification mainly focus on national values. The interviewed ERTMS expert indicated that the so-called technical national rules are equally as important for changeability. The introduction of these rules do not require that existing vehicles comply to them. However, he states: “Updating rolling stock could result in the necessity to comply to various newly introduced National Technical Rules of the countries where the rolling stock operates in. This is a hindrance for adaptability.” (appendix F.23). For example, if the new FRMCS network on Kijfhoek – Roosendaal also inserts new national technical rules, all newly updated vehicles in Europe that operate on this corridor must comply to these Dutch rules. This decreases the business case for new updates, thus decreases the adaptability.

8. Conclusion and discussion

This final chapter concludes this thesis with the integrated and validated strategy for increasing adaptability. Section 8.1 will start by answering the four sub-questions from section 1.3 and provides corresponding sections where additional information can be found. Thereafter, the main research question is answered by providing the validated strategy categorized in the three topics that are identical to the topics chosen in chapters 6 and 7. The validated strategy will provide an advice for each topic to strengthen the adaptability to future rail operational needs. Section 8.2 will provide a discussion that recommends topics for further research into the scientific and societal gaps exposed by this thesis.

8.1 Validated strategy for increasing adaptability

This section answers the main research question by providing a validated strategy that strengthens the adaptability of the Dutch implementation of ERTMS towards the future. Before this strategy is given, the four sub-questions necessary to provide an answer to the main question are described and answered:

1. Sub-question 1 - Which factors influence adaptability?
   This sub-question is answered by identifying various adaptability factors in the literature review (section 2.5) and the three case studies (section 5.4). The gathered factors are shown in Table 23 with corresponding description.

Table 23: Summarised factors that influence adaptability (sections 2.5 and 5.4).

Factor	Description
Stakeholder involvement	The involvement of various different stakeholders increases sector-wide support for decisions thus decreases the need for adaptability.
Process clarity	Improving the clarity in the implementation process by providing information for preparation of stakeholders through road mapping or a simulator.
Leadership	Strong leadership ensures integrity and purpose in the process.
Flexibility management	Preserve the ability to change direction with respect to technology and governance.
Modularity	The ability to replace or implement components without requiring to modify existing components.
Standardisation	For interoperability, ensure standardisation in interfaces and components.
Operational compatibility	A technological implementation might also have an effect on operational aspects.
Technology updating	Necessary technological changes after implementation of components that contain errors.
Future needs	Requirements due to upcoming innovations.

2. Sub-question 2 - Which components of ERTMS are prone to developments in the near future?
   This sub-question is answered by performing a development analysis in chapter 4 and modelling the innovations to acquire insights in their effects on the Dutch implementation of ERTMS. The components of ERTMS that are prone to developments in the near future are:
    - The TMS should allow interfacing with a C-DAS or ATO trackside component.
    - The RBC should be able to interface with the FRMCS network.
    - The CSS should be able to operate under ETCS HL3.
    - The EVC should be able to provide output to other on-board components and be prepared for integration of additional functionalities needed for virtual coupling.
    - The Euroradio should be able to interface with the FRMCS network.
    - The DMI should be able to visualize additional data from ATO or virtual coupling

3. <u>Sub-question 3 - How can these factors be translated into solutions that strengthen the adaptability of ERTMS to future developments?</u>
   This sub-question is answered in chapter 6 by translating and merging the adaptability factors and critical issues to form the proposed solution that strengthen the adaptability of ERTMS. These proposed solutions are given summarized in Table 24.

Table 24: Summarised proposed solutions provided from the ERTMS adaptability analysis (chapter 6).

Technological implementation		
Topic	***Critical issue***	**Proposed solution**
ERTMS baseline management	*ERTMS baseline updates are expected in the future but these standards are until now not fully compatible and experiences maturity issues.*	Choose a dominant standard and tender, using small regions and with transparency, with a new standard. This new standard must be considered mature enough and backwards compatibility is ensured.
ETCS application level management	*ETCS application levels have an effect on the requirements for necessary track and on-board components.*	Transparency is important in choosing the application level. Furthermore, let ETCS HL3 be a sector-wide driven innovation and include it in the official specifications.
Interface management	*ERTMS and its interfaces are continuously evolving with changing needs and possibilities.*	New interfaces must be enabled through modularity using standardisation and facade patterns.
Component management	*Required components of upcoming innovations could have overlap or incompatibility between them or with existing components.*	Prepare various components for the integration or cooperation with additional components. More information can be found in section 6.2.4
Governance and stakeholder management		
Topic	***Critical issue***	**Proposed solution**
Position program ERTMS	*The program is sensitive for the interests of a single or a selection of stakeholders.*	Balance stakeholder involvement by stimulating a diverse group of employees in the ERTMS program and give the means necessary for the program manager of Min I&W to function as central leader.
Stakeholder involvement	*Cooperation and coordination between stakeholders such as involved actors, experts and interest group or end users.*	Increase sector-wide support for decisions by involving stakeholders with informal interaction, a comprehensive roadmap, organized meetings and joint KPIs.
Generation of support	*Interconnection between stakeholders and support of ERTMS and upcoming innovations.*	Improve interconnection and support by appointing ambassadors, organizing meetings and creating visualizations.
Changeability in contract	*Decreased changeability due to contract setup or static policies.*	Preserve adaptability in the contract by rewarding changeability and by preserving flexibility in applicable policies.
Financial and regulatory adaptations		
Topic	***Critical issue***	**Proposed solution**
Availability of budget	*Marginal technological changes are considered expensive.*	Acquire sufficient budget to cover necessary marginal technological changes.
Certification	*Changing national values result in the necessity to entirely re-certifying vehicles.*	Change the certification approach by certifying a vehicle against a range of national values instead of only the applicable value.

4. <u>Sub-question 4 - How does these solutions perform in a probable use case?</u>
   This sub-question is answered in chapter 7 where the proposed solutions are validated in a use case where FRMCS-only is implemented through a TSI update on the Kijfhoek – Roosendaal corridor. Three experts with various areas of expertise checked the solutions on their validity. One outcome is that a main shortcoming of the technical adoptions is the restraint of the signalling industry to sell components that are prepared for new innovations without official documents. Draft documents are conceived as insufficient. For this reason,

the solution to establish a modular system is endorsed. The experts further indicate that there is an absence of the use of the entire range of instruments available to provide a good governance and stakeholder management. Involvement and transparency is endorsed but could prove ineffective when not combined with firm and proper use of instruments such as regulations and obligations. The main endorsement is the creation of a comprehensive roadmap that provides information on the various aspects of the Dutch ERTMS implementation. Finally, the interviewed ERTMS expert introduced the negative effect of technical national rules on adaptability in addition of the already specified national values. In other words, an update of the on-board equipment can imply that this equipment must meet various additional, newly established rules of other European countries. This decreases the business case for each update.

With all sub-questions answered, an answer to the main research question can be formulated.

"Which strategy can be chosen to strengthen the adaptability of the Dutch implementation of ERTMS to future rail operational needs?"

The strategy that answers the main research question is given in the following three sections. Section 8.1.1 starts by providing a strategy to improve technical adaptability. Section 8.1.2 provides a strategy surrounding governance and stakeholder management. Finally, section 8.1.3 provides a strategy for financial and regulatory aspects that improves adaptability. A roadmap of the integrated strategy is given in Figure 25. This roadmap provides a suggestion on how the strategy can be adopted. It starts by forming the governance necessary where adaptability is supported and stakeholders are well involved. With this, developments can be observed and decided for in a transparent manner. If a

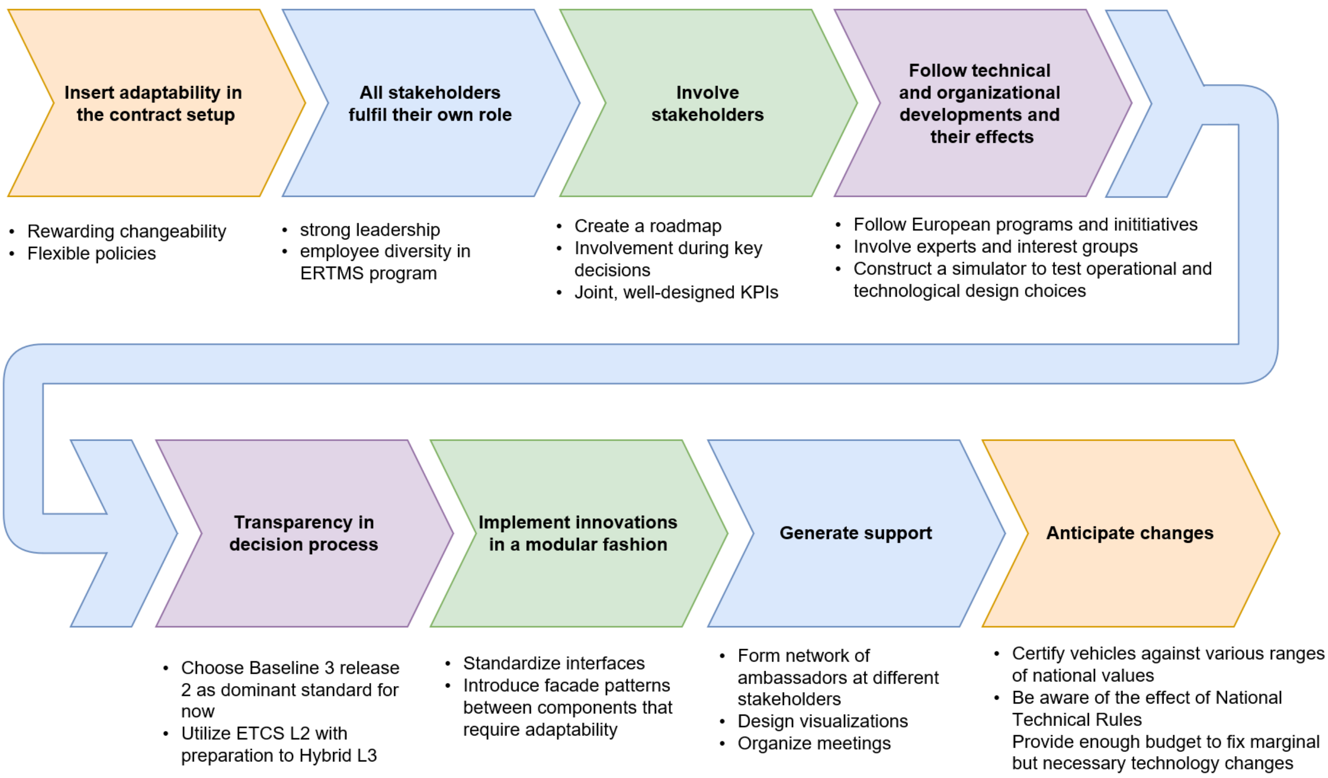

Figure 25: Suggestion for a roadmap to adopt the strategy to strengthen the adaptability for the ERTMS implementation

certain choice is made, it must be in a modular fashion and with support of the stakeholders. Finally, the program should anticipate on changes. Further information can be found in the following sections.

8.1.1 Strategy for the technological implementation

This section will provide a validated strategy for increasing the technical adaptability of the planned Dutch ERTMS implementation. As in section 6.2, the topics are as follows: ERTMS baseline, ETCS application level, interface and component management. The substantiation of this strategy is based on the solutions given in section 6.2 amended according to the additional comments provided in the use case in section 7.2. A suggestion for a roadmap of the integrated strategy is shown in Figure 25.

A clear and transparent ERTMS baseline management is advised. Therefore, as described in section 8.1.2, stakeholders should be transparently involved in decision-making and the roadmap through ERTMS baselines should be clear. This means the following: the use of a dominant version of the TSI, in this case B3R2, is advised for the currently planned trackside ERTMS implementation. While new TSIs are expected in the coming years, only update or implement with a new TSI on the infrastructure if this version is considered mature enough, with respect to developments during that time, and when total backwards compatibility can be ensured. To preserve flexibility, for instance if this new TSI unexpectedly does contain errors, tender equipment for small regions only and use this as exercise of team learning.

ETCS application levels, as with described in the previous paragraph, require a clear and transparent management. These levels have an effect on the rail capacity through the insertion of desired or required on-board components. While official communication from the program partners suggest an implementation of ETCS L2 with preparation towards ETCS L3, it is more accurate to communicate that the program is preparing towards ETCS HL3 instead of ETCS L3 as specified in the ERA specifications. For this implementation, it is advised to let ETCS HL3 be a sector-wide driven innovation with adequately risk management by involving other stakeholders in this innovation process as described in section 8.1.2. Furthermore, it is advised to include ETCS HL3 in the official specifications.

It is advised that the implementation of ERTMS should prepare components to be interfaced to new components necessary for the innovations described in section 4.2. An important proposed solution to accomplish this preparation, is to introduce modularity between components using standardisation and facade patterns. The latter is explained in section 3.6.4. Modularity improves adaptability, financial lifespan and pricing. This solution is extra important because the industry is reluctant to prepare a requested component, like an Euroradio, for an interface with an upcoming innovation, like FRMCS, without official specifications. Draft documents are considered as insufficient. However, when official specifications for these innovations are issued, direct preparation should be set in motion. This is especially important for the following interfaces due to their relevance in light of upcoming innovations (Figure 23):

- Prepare the RBC for bi-directional messages through the FRMCS network.
- Prepare the Euroradio for bi-directional messages through the FRMCS network.
- Prepare the EVC to provide output towards a C-DAS and ATO on-board.
- Prepare the TMS for an interface with a trackside C-DAS or a trackside ATO.
- Prepare the EVC for integration of functionalities needed for Virtual Coupling.

Furthermore, various future innovations are affected by the overlap and synergies between existing and future components. If the overlap and synergies are known, a future-proof and efficient implementation of ERTMS can be ensured. For this to be known, it is important to closely follow European programs and initiatives such as Shift2Rail, EULYNX, RCA and OCORA and involve stakeholders such as experts and interest groups as described in section 8.1.2. Furthermore, to acquire knowledge about overlapping effects, operational and technological choices must be tested in a simulator. In order for the ERTMS implementation to be more future-proof, the following design choices and considerations are advised due to their relevancy in light of upcoming innovations (Figure 23):

- Make sure that the CSS can be converted to operate under ETCS HL3.
- If needed, choose for a migration towards FRMCS over enhancing the GSM-R network.
- The DMI must be able to visualize additional information (ATO on-board and enhanced MA).
- Use a C-DAS as bridge towards implementation of ATO GoA 2.
- Prepare the on-board equipment for additional components like the additional antenna for Virtual Coupling, the ATO or C-DAS on-board and a dedicated HMI.

An important factor to take into account for these design choices and considerations, is that they are dependent on technical maturity of the involved innovations and on the applicable asset management strategy.

8.1.2 Strategy for governance and stakeholder management

This section will provide a validated strategy for increasing the adaptability with respect to governance and stakeholder management of the planned Dutch ERTMS implementation. As in section 6.3, the topics are as follows: position program ERTMS, stakeholders involvement, generation of support and changeability in the contract. The substantiation of this strategy is based on the solutions given in section 6.3 amended according to the additional comments provided in the use case in section 7.3. A suggestion for a roadmap of the integrated strategy is shown in Figure 25.

The position of the program ERTMS with ProRail has been analysed to determine its independency that is required by the Ministry in light of the described principle-agent problem. It is advised to examine the current fulfilment of the different roles in the governance model to ensure a balanced decision-making process in light of stakeholder interests. The program manager of Min I&W should function as capable counterpart to the program management team with corresponding checks and balances and should acquire the technical knowledge and resources required to do so. In this role, not only non-binding measures should be used but the entire range of instruments available to execute proper and firm governance such as regulations, obligations, agreements and subsidies

Stimulation of involvement of stakeholders can be an important factor in improving cooperation and coordination. This is important due to the nature of the implementation of ERTMS, as complex system integration with a range of different responsibilities and interests. The most endorsed solution advises the introduction of a comprehensive roadmap that specifies information on planning, status and key design decisions, such as the implementation of innovations. This can be used for proper preparation by stakeholders and can be established by closely following ERTMS programs, initiatives and experts as mentioned in section 8.1.1. This roadmap should be kept, with respect to planning and direction, to provide legal certainty to decrease the chance for financial damage claims. Besides involving main stakeholders like railway undertakings and infrastructure managers, it is advised to also involve stakeholders such as end users, experts and interest groups through organized meetings when key design decisions are made to ensure a more sector-wide supported decision. Through these organized meetings, employees of different stakeholders should interact in an informal manner on a frequent basis. Finally, to further improve cooperation and coordination, joint KPIs could be introduced. However, the structure of this KPI should be well-designed to avoid negative side effects.

It is advised to generate support for the implementation of ERTMS. This support allows interconnection between different experts and could reduce the negative effect of arising issues. A network of ERTMS ambassadors could be appointed at different stakeholders. Various meetings could be organized to explain current functionalities and future possibilities substantiated by visualizations such as infographics or movie clips.

Finally, it is advised to insert changeability in involved contracts. As mentioned earlier, the introduction of KPIs could improve on cooperation and coordination. However, as seen in the case study on the HSL-Zuid, it could also result in indirectly penalizing changeability. It is advised to make sure that the contract does not penalize changeability but reward it.

8.1.3 Strategy for financial and regulatory adaptations

This section will provide a validated strategy for increasing the adaptability using other measures for the planned Dutch ERTMS implementation. As in section 6.4, the topics are available budget and certification and acceptance. The substantiation of this strategy is based on the solutions given in section 6.4 amended according to the additional comments provided in the use case in section 7.4. A suggestion for a roadmap of the integrated strategy is shown in Figure 25.

It is advised, in line with EC auditors in 2017, that sufficient budget is freed to deal with marginal technological changes that could be necessary but are conceived to be rather expensive.

From the research in this thesis, it is shown that national values and national technical rules have a large effect on adaptability of ERTMS. It is advised to certify and accept new on-board train equipment against various applicable ranges of national values instead of only the currently used national values. Furthermore, it is advised to be aware of the effect that the changing national technical rules could have on rolling stock. These subjects are not researched extensively in this thesis and are recommended for further research in section 8.2.

8.2 Discussion and recommendations

This thesis has identified factors and solutions that affect adaptability of ERTMS which are complex and would require further research to assess the extent of their effect and the instruments available to influence these factors. This section suggests a few topics that are recommended for further research.

As ERTMS is a complex and continuously evolving system, the provided strategy could prove ineffective if unforeseen developments occur. It is necessary, in time, to perform further research if the used sources are still viable and applicable for that scenario.

Research is recommended in the creation of a roadmap. All experts that validated the use case endorsed the solution to establish a comprehensive roadmap that provides information on the planning, status, coming new innovations and their effects. This roadmap could also describe overlap and synergies between these innovations. This information should provide legal certainty for stakeholders to prepare on. While this thesis does research the effects, it did not produce a plan of the upcoming innovations.

Research is recommended in the establishment of modularity. The need for modularity is an important outcome of this thesis. European programs and initiatives such as Shift2Rail, EULYNX, RCA and OCORA are working on standardisation and facade patterns that allow systems to be loosely coupled, introducing modularity. Further research is needed on this subject. Especially on modularity in components necessary and affected by new innovations that are likely to be officially inserted in the TSI in the coming years, like ATO or FRMCS.

The effect on interfaces and components resulting from the implementation of upcoming innovations are researched in this thesis (section 4.2). However, these effects are based on architectures, designs and documentation that are not yet officially established or proven. In other words, the various design choices and considerations for each innovation made in this thesis could differ in the future. Further research is needed on each innovation to assess its effect on the Dutch, or any other, implementation of ERTMS.

As mentioned in the previous section, further research is needed on the effect of national values and national technical rules on adaptability of ERTMS. This thesis lightly touched on the issue that changing national values or national technical rules could have on ETCS on-board equipment that operates in multiple European countries.

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Appendices

Strengthen the adaptability of the ERTMS implementation

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Abstract— **The number of operational rail corridors equipped with ERTMS is increasing throughout Europe. The implementation of this critical safety system is planned to take several decades. However, ERTMS is a complex system that evolves continuously increasing the risk of using outdated parts and components. Therefore, adaptability is required for an efficient process. Adaptability is the ability of a system to meet technological or functional changes without requiring structural modifications or replacements. This paper identifies factors that influence adaptability and researches critical issues for future adaptability of ERTMS. With these factors and issues, solutions are proposed that are validated in a use case and integrated in a strategy that strengthens adaptability of ERTMS for future operational needs. The main takeaways of this strategy is the need for technical modularity and a balanced stakeholder involvement in the implementation process.**

Keywords: ERTMS, adaptability, future-proof, innovation, SysML, ETCS, GSM-R, FRMCS

I. Introduction

In Europe, transport and travelling cause almost 25% of the total greenhouse emissions (Eurostat, 2019). The modes that contribute most to this percentage are road transport and civil aviation. Furthermore, the use of these modes have increased tremendously in the past twenty years and this growth is expected to continue. To counteract this trend, the European Commission envisions a Europe in which the high-speed train is the standard transport mode for connecting cities as stated in their Strategic Rail Research Agenda for 2020 (ERRAC, 2007; EC, 2016). Two of the challenges to accomplish this goal is alignment and interoperability in Europe's rail infrastructure. The chosen solution for these challenges is the implementation of a standardized railway safety system called the European Rail Traffic Management System (ERTMS).

ERTMS is a complex system that evolves continuously while member states, like the Netherlands, plan more than thirty years for its implementation. This introduces the risk of implementing outdated components. Therefore the system must be implemented in an adaptable manner. Adaptability allows a system to meet technological or functional changes without requiring structural modifications or replacements. The implementation of ERTMS is done throughout Europe, with changing and rather unknown technological, operational, business and regulatory developments. This situation creates the necessity for up-to-date research on this topic.

The objective of this paper is to identify essential issues of ERTMS that trigger adaptability for future configurations of the Control Command and Signalling (CCS) as well as factors to various aspects of adaptability. With these issues and factors, a strategy is formed for strengthening the adaptability of an ERTMS implementation for future rail operational needs. This strategy is based on the most recent developments in technological, organisational, regulatory and financial aspects in the rail sector. This strategy is tailored to the Netherlands as it is chosen as case for this paper. This paper contributes to the knowledge surrounding adaptability by providing general factors that hinder or stimulate adaptability. Furthermore, comprehensive SysML modelling of ERTMS has enabled the identification of criticalities in current ERTMS specifications that trigger adaptability and compatibility issues in the future with deployment of innovations. This paper has identified solutions that are integrated into a strategy. This strategy provides a set of actions that are needed to be adopted by stakeholders to future-proof ERTMS with respect to governance and technology.

II. Literature

How to deal with uncertainty in transport planning and policy making is a subject that is treated extensively in literature. However, the way in which uncertainty is addressed changed in the last thirty years. While Khan (1989) argued that transport planners were urged to view forecasts with a lot of caution and that rigid transportation plans with a horizon of more than 20 years should not be seen as realistic, Navarro et al. (2019) suggested that the uncertainty issue can be addressed in a heuristic framework that prevents uncertainty dimensions to be too elusive or meaningless. Lyons and Davidson (2016) even suggested that uncertainty is an opportunity for decisionmakers to realise that they are shaping the future instead of only reacting to a prediction. Another method to address uncertainty is with adaptability and flexibility (Gifford, 1994). Salet et al. (2013) further builds upon this argument and suggests four pointers to increase adaptability which are individually confirmed by other researchers. The first pointer is the ability to re-frame the strategic mission to match developments Edmondson (2003). The second pointer the mobilization of the institutional capacity and its necessary cooperative alignment (Maull et al., 2015). The third pointer is the identifications of robust

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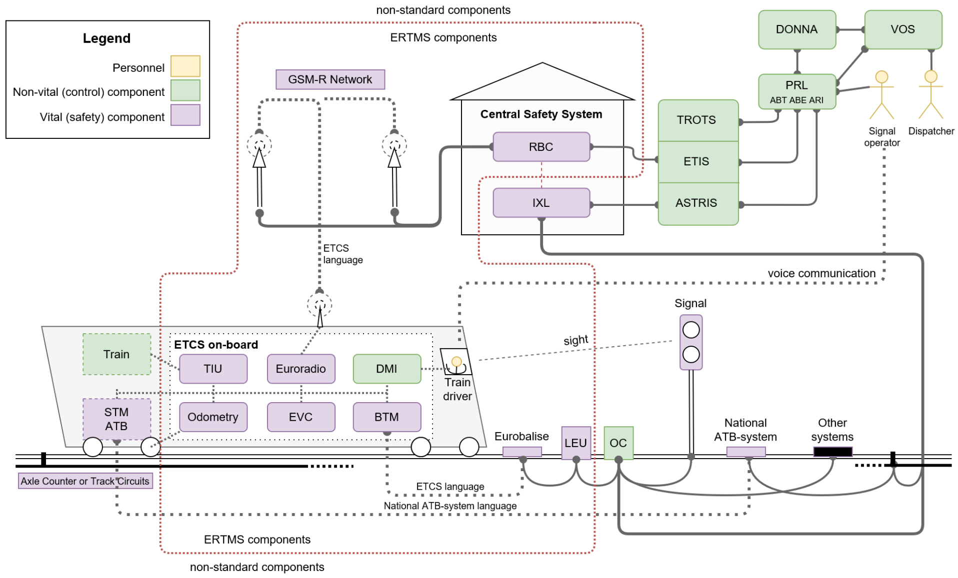

Fig. 1. Sketch of used components in the planned Dutch ERTMS implementation

and flexible policy options (Marchau et al., 2008; Ramjerdi & Fearnley, 2014). Finally the installation of a simulation to test operational and technological choices (Giezen et al., 2014).

Sanchez and Mahoney (1996) argues that adaptability can also be strengthened by introducing modularity between subsystems that are likely to change. This is confirmed by Domingues et al. (2015). Modularity can be introduced with facade patterns and standardisation. The terminology of a facade pattern is used in a book on software design by Larman (2002). A facade pattern can be defined as an object-oriented design layer whereby systems are loosely coupled such that either system is little affected by changes beyond this introduced layer. This layer provides means to connect systems using a single point of contact (Larman, 2002). Tassey (2000) argues that standardisation of constructs can ensure proper interoperable parts. However, he argued that a single standard must be dominant, well-designed and well-timed so that technological updates are not necessary. This argument is confirmed by Maull et al. (2015). For the standard to be well-designed and well-timed, it is important to include stakeholders in the decision making in a collaborative manner. For this, Ho and O'Sullivan (2017) suggest roadmapping as proven tool. This is confirmed by Hasberg et al. (2012). Ho and O'Sullivan (2017) suggest that roadmapping can be used as coordination tool for the government. Kearns et al. (2005) confirms the necessity of a strong central leader to maintain integrity and purpose. Finally, Klein and Knight (2005) argue that a focus on operational aspects during a technological implementation can improve the effectiveness and efficiency of the process.

III. ERTMS

ERTMS establishes a standard for the railways throughout Europe in such a way that these are interoperable. In this standard a train with ERTMS on-board equipment can run on corridors equipped with ERTMS trackside equipment. Currently, mainly consists of two subsystems. The first is ETCS (European Train Control System), which is a train control standard. ETCS is able to supervise movement and can stop a train if the speed exceeds a maximum speed based on a corresponding calculated braking curve or a specified speed ceiling. The second subsystem is GSM-R (Global System for Mobile Communications – Railways). This refers to the current radio communications standard used for railway operation (ERA, 2016). An overview of the components used and interfaced in the Dutch implementation can be seen in figure 1. The definitions of the notable components in this figure are given in table I (Westerhuis, 2020).

TABLE I
DEFINITION OF NOTABLE COMPONENTS OF FIGURE 1

Name	Description
EVC	European Vital Computer. The vital core of the ETCS on-board device which provides the logic for train protection and supervision. It interacts with other ETCS train components.
GSM-R	Global System for Mobile Communication – Railways. This vital system provides a method for ERTMS to transmit data between track and train.
CSS	Central Safety System. The integration of the IXL and RBC that is specified in the Dutch ERTMS program (Programma ERTMS, 2018).
IXL	Interlocking. A vital non-standard cluster of trackside systems each intended to control the setting and release of routes and points to prevent unsafe conditions.
RBC	Radio Block Centre. A vital standardized trackside unit which receives data on train positions and interacts with the IXL to formulate messages, such as MA's, to trains.
PRL	Procesleiding (Process Management). Non-vital software that functions as TMS which, based upon a predetermined plan, sets routes for trains.
ATB	Automatische Treinbeïnvloeding (Automatic Train Protection). The Dutch national class B system.

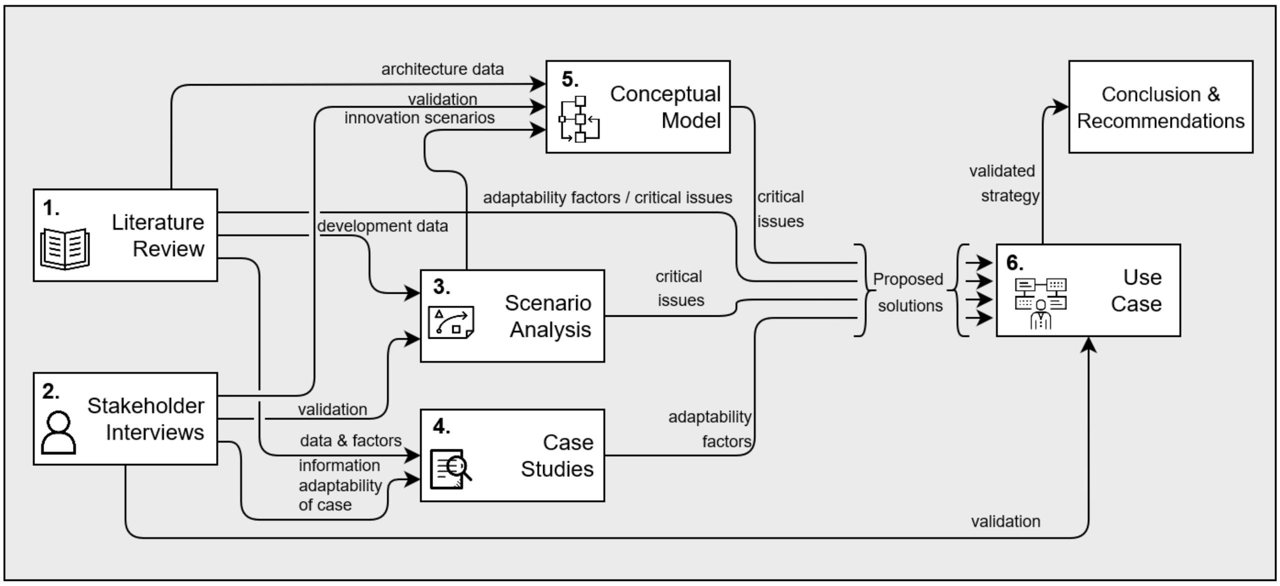

Fig. 2. Methodology of the research: the six steps

In figure 1, a distinction is made between standardized ERTMS components and non-standard components. The components that are located outside the red dotted boundary are not specified in the TSI and are non-standard. Furthermore, the figure provides classification between personnel, non-vital control components and vital safety components. Each component that is responsible for ensuring that safety measures are respected falls within the latter classification. This distinction provide means to identify components that are difficult to change. ERTMS is documented in a set of specifications, called Technical Specifications for Interoperability (TSI). The European Railway Agency (ERA) provides updates to these specifications in the form of baselines and/or releases. Currently there are three official sets which contain documents specifying aspects, components, interfaces, etc., concerning the architecture of ERTMS. These documents specify the boundaries to which suppliers of the technical systems are required to comply. General compatibility between baselines is not ensured. Compatibility is ensured with only higher or equal versions of the on-board unit (OBU) on lower or equal versions of the trackside.

IV. METHODOLOGY

This paper follows six steps that are visualized in figure 2. The research start by identifying adaptability factors and critical issues in the first five steps. This paper introduces the term adaptability factor as a generalized factor that influences adaptability. Critical issues are criticalities in the current ERTMS implementation that might trigger adaptability and compatibility issues in the future with respect to technological, organizational, financial or regulatory developments.

The first step is the literature review. This review provides the base substantiation for the other steps and identifies adaptability factors. In the second step stakeholder interviews conducted for further substantiation or validation for the other steps. The summarised interviews are provided in the linked master thesis (Westerhuis, 2020). The third step is the scenario analysis where upcoming developments of ERTMS are identified. The fourth step is the assessment of three case studies; the construction of the HSL-Zuid, the implementation of RouteLint and of the OV-Chipcard. These case studies are meant to affirm adaptability factors identified in the literature review in real-world examples. The information required for this step is acquired through literature and stakeholder interviews.

The fifth step is to create a comprehensive conceptual model for the Dutch ERTMS implementation and a variation for each foreseen development identified in the third step. The semi-formal method used to visualize the system is System Modelling Language (SysML). SysML is a dialect to Unified Modelling Language (UML) and can be used for explaining a systems architecture. This method is ideal for providing insight in complex systems that consist of multiple subsystems. SysML is therefore perfectly suited to model the Dutch ERTMS implementation to provide a way of analysing detailed impact of foreseen innovations.

The identified critical issues and adaptability factors are used to propose solutions for strengthening the adaptability of the ERTMS implementation for future operational needs. These solutions are tested in the sixth step on their effectiveness in a use case and validated by three experts with different areas of expertise through stakeholder interviews. This use case simulates the implementation of FRMCS-only with a necessary infrastructure update towards the next set of specifications on the Kijfhoek - Roosendaal corridor after ERTMS is implemented conform the proposed solutions. With this validation, the solutions can be integrated into a validated strategy.

V. Results

This section presents the results of this research. The first subsection starts by providing the adaptability factors identified in this research and a description of the three case studies. This description also provides the confirmation given of the adaptability factors by the cases. In the following subsection, critical factors are presented that are identified in the comprehensive SysML modelling of ERTMS and its current foreseen developments. The third subsection presents the proposed solutions that are formed on the adaptability factors and the critical issues. This subsection also provides the validation of these solutions by the experts. The final subsection presents the integrated strategy that is composed based on the previous subsections.

A. Adaptability factors

The literature review in section II provides adaptability factors that are tested in three case studies. These case studies each test the adaptability mechanism of the factors in real world examples. The factors are shown in table II. The case studies are: the construction of the HSL-Zuid, the implementation of RouteLint and the implementation of the OV-Chipcard. The stakeholder interviews used to confirm the adaptability factors can be found in the linked master thesis (Westerhuis, 2020).

TABLE II

Factors that influence adaptability

Factor	Description
Stakeholder involvement	The involvement of various different stakeholders increases sector-wide support for decisions thus decreases the need for adaptability.
Process clarity	Improving the clarity in the implementation process by providing information for preparation of stakeholders through road mapping or a simulator.
Leadership	Strong leadership ensures integrity and purpose in the process.
Flexibility management	Preserve the ability to change direction with respect to technology and governance.
Modularity	The ability to replace or implement components without requiring to modify existing components.
Standardisation	For interoperability, ensure standardization in interfaces and components.
Operational compatibility	A technological implementation might also have an effect on operational aspects.
Technology updating	Necessary technological changes after implementation of components that contain errors.
Future needs	Requirements due to upcoming innovations.

The construction of the HSL-Zuid

This case study affirms the necessity of flexibility management, stakeholder involvement and process clarity (Westerhuis, 2020). The High Speed Line between Amsterdam and the Belgian border opened in 2009 and is 85 kilometre. It is part of the European high-speed train network and is meant for international passenger transport. The HSL-Zuid is constructed under a DBFM contract (Design, Build, Finance and Maintain) and is currently in the maintain phase of 25 years with formal completion in 2031. This contract enforces the contractor to optimize safety and availability through the means of a penalty system (Hoogzaad & van Ham, 2006). A so-called State Variation Proposal (SVP) can be used by the Dutch government to make a change on the HSL-Zuid. The contractor is required to oblige. However, every change could have an impact on risks surrounding safety and availability which could, in turn, result in a penalty. For this reason, the contractor and its shareholders are averse to additional risks and thus potentially opposed to changes. Every SVP could lead to a discussion about scope, costs and delivery time (Decisio, 2020). This process is a consequence of a form of contract where individual risk minimization is stimulated. Furthermore, this led to decreased trust between stakeholders which led, among other reasons, to insufficient risk management (Algemene Rekenkamer, 2007).

The implementation of RouteLint

This case study affirms the necessity of standardisation, modularity, stakeholder involvement and operational compatibility (Westerhuis, 2020). RouteLint is originally devised by ProRail as a Driver Information System (DIS) application to improve cooperation between dispatchers and train drivers. It started out as idea in 2003 to create a link providing real-time network information from the Train Management System (TMS) to the driver (van Luipen, 2019). The data transmitted between the TMS and the device operating RouteLint is standardised and established in a modular fashion. This allowed train operators to develop their own application on their own device using the RouteLint data that is harvested in the ProRail TMS. The Dutch Railways, for instance, further developed RouteLint on their TimTim into a simple driver advisory system (DAS) by using the RouteLint (Emerce, 2018). Besides this standardised and modular setup, a lot of effort was put into stakeholder management and generation of support. The generated support and early involvement of the end users in the design process led to a decreased need for adaptability. The involvement of end users confirms the necessity for operational compatibility besides the technicalities of such an innovation.

The implementation of the OV-Chipcard

This case study affirms the necessity of standardisation, leadership, stakeholder involvement and flexibility management (Westerhuis, 2020). The Dutch public transport sector desired a national payment system to modernize ticketing that led to the establishment of Translink Systems (TLS) in 2001. TLS was established by five large passenger operators (Connexxion, GVB, HTM, NS and RET). TLS requested a multi-vendor solution to the market that required the contractor to provide an open architecture for other suppliers to connect to the payment system afterwards. The establishment of an open standard neutralized the possibility of a vendor lock-in. The implementation started as pilot in Rotterdam instead of implementing in various locations within the Netherlands. This increased the flexibility to detect and fix unforeseen issues. The payment for this system came mostly from a large fund that was allocated to ProRail and NS by the

Dutch government for their sold telecom shares. NS allocated most of their share into this system resulting in the fact that NS became heavily represented as shareholder (68.75% of the shares in 2008 (ACM, 2013)). This gave NS the strategic advance in their ability to prioritise issues during the implementation process. This led to distrust between parties and the idea that operators were treated unequally by TLS and the Dutch government (Veeneman et al., 2011). The government could have served as harmonizing factor, functioning as recognized central leader.

B. Critical issues

Critical issues are assessed by modelling a variation of the conceptual model shown in figure 3 based on the foreseen innovations. The conceptual model used as start is based mainly on the ERA specifications. More specifically, baseline 3 release 2 (B3R2) SRS 3.6.0 with ETCS application level 2 as this is the chosen setup in the Netherlands (ERA, 2016). For further tailoring the model to the Dutch situation, the architecture provided by the Dutch ERTMS program and the technical reference architecture by ProRail are used for input (Programma ERTMS, 2018; ProRail, 2018). To validate the model, multiple experts of the different subsystems are consulted to provide their view on the model. The interviews with these experts along with further substantiation of the model can be found in the linked master thesis (Westerhuis, 2020). The innovations are identified and assessed using literature and stakeholder interviews. The chosen design choices that correspond to the implementation of each innovation in the model is based on available draft documentation and architectures. Because FRMCS, as innovation, is used for the simulation in the use case, the model with FRMCS is included in this research paper (figure 4. The variations of the conceptual model for the other innovations are described and shown in the linked master thesis (Westerhuis, 2020).

ETCS Hybrid level 3 (HL3)

The main difference between ETCS L2 and L3 is the requirement that individual train integrity is determined by on-board train equipment (ERA, 2016). The device that provides this integrity is called a train integrity monitoring (TIM) system. The implementation of this device is technically more difficult to establish for freight operators (EUG, 2018). This is a hindering factor for implementation of ETCS L3. Network Rail and ProRail proposed an initiative that mixes ETCS L2 and L3 with fixed virtual blocks and a decreased dependency on trackside systems (Furness et al., 2017). This concept is called ETCS Hybrid level 3 and allows trains to operate with and without a TIM system (EUG, 2018). Before ETCS HL3 can be utilized optimally, the majority of the trains must contain a TIM system, the RBC must be able to construct fixed virtual block sections and the IXL must utilize these blocks for correct setting and release of points and signals (Senesi et al., 2018). The TMS must also be able to set routes with these virtual blocks (Westerhuis, 2020).

3kV railway electrification (3kV)

As described in the introduction, a rather large portion of greenhouse emissions is caused by the transport sector. The train only contributes a small percentage to this portion. ProRail and NS argue that it could improve even more if rail operations run on 3kV instead of the currently used 1.5kV (ProRail & NS, 2018). The requested voltage is linked to the ETCS equipment through the train interface unit (TIU). Following article 7.5.1.78 in subset-026, the traction system voltage is configurable for ERTMS (ERA, 2016). This makes ERTMS adaptable towards this innovation (Westerhuis, 2020).

Future Railway Mobile Communication System (FRMCS)

The planned Dutch ERTMS implementation is currently solely based on GSM-R. Support for GSM-R from the industry is likely to end between 2028 and 2030 (EIM, 2019). Therefore, preparations should be made towards a next generation network system. For this, however, a standard for this next generation network system must be issued by the ERA because all current specifications are based upon a single baseline of GSM-R. The next set of specifications is expected in 2022 which is likely to include a migration strategy and alternative for GSM-R (Ruete, 2020). The system that is most likely to be included in this next set is the Future Railway Mobile Communication System (FRMCS). For this system to be implemented, various challenges must be overcome. An entire network must be setup that can provide at least similar bandwidth with equal functionalities as the GSM-R network. The RBC and FRMCS network must be interfaced. The trains must require a multimode to allow operation with GSM-R and FRMCS as suggested by the European Rail Infrastructure Managers (EIM, 2019). The EIM (2019) suggest, among other options, a FRMCS gateway and adaptation of the Euroradio to utilize both signals (Westerhuis, 2020). The conceptual model where FRMCS is implemented is included in this paper (figure 4). The components and interfaces indicated in red are affected by the implementation.

New Traffic Management System (TMS)

A TMS has various objectives. It sets routes for trains and detects and solves conflicts by continuous train movement monitoring. Currently, this task is performed in the Netherlands by PRL as described in section III (ProRail, 2019). According to sources, PRL would not allow optimal utilization of foreseen innovations like a C-DAS or ATO (Rao et al., 2012; Westerhuis, 2020). Therefore, ProRail is currently researching a new TMS which integrates the traffic management function into one centralized TMS instead of the now thirteen decentralized systems. The impact of a new TMS is limited due to the software interfaces in the Traffic Control System (TCS) that are provide the interface between the TMS and ETCS trackside equipment. These interfaces function as facade pattern as explained in section II. However, the planning system must be changed to manage this single centralized system (Westerhuis, 2020).

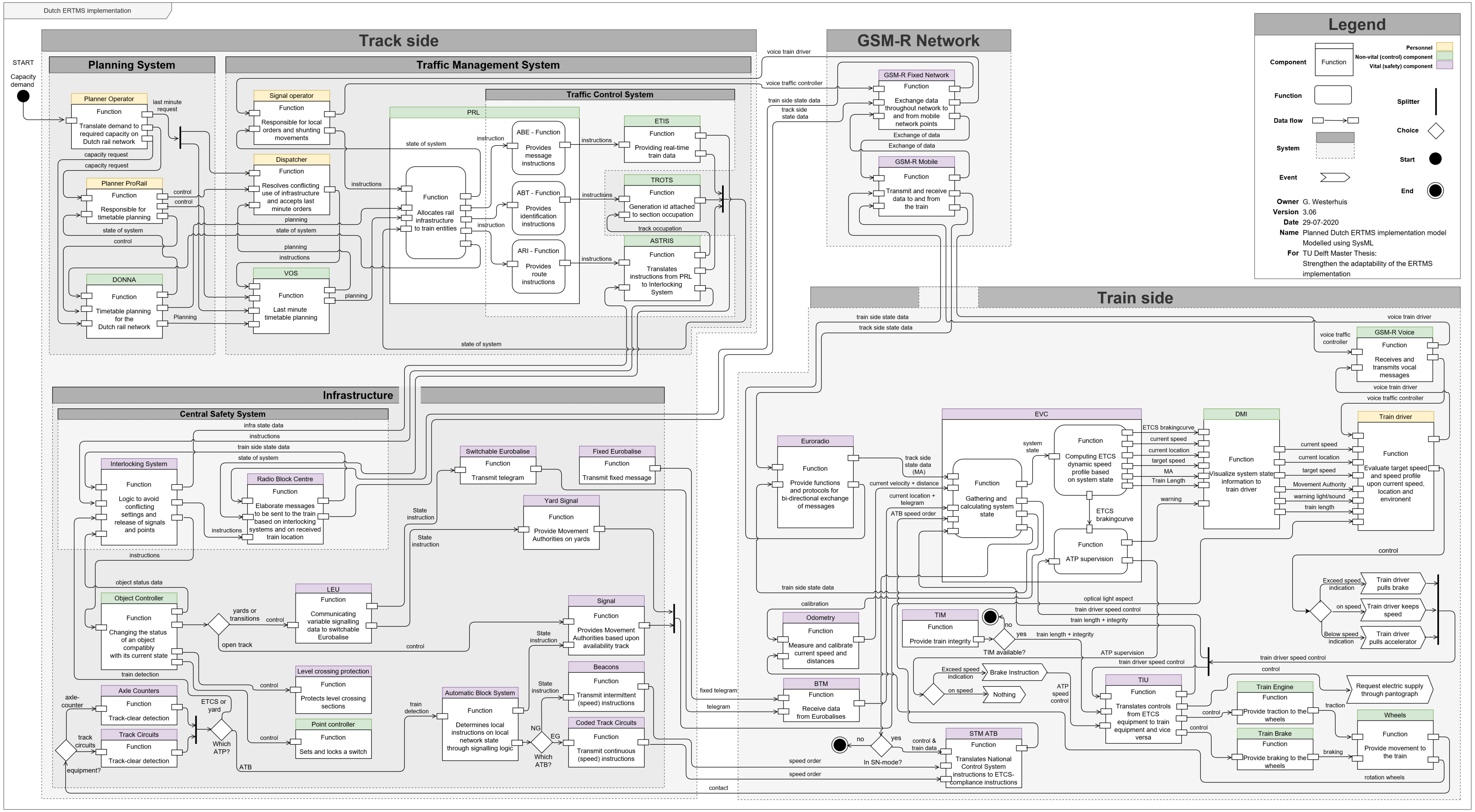

Fig. 3. The Dutch implementation of ERTMS visualized using System Modelling Language.

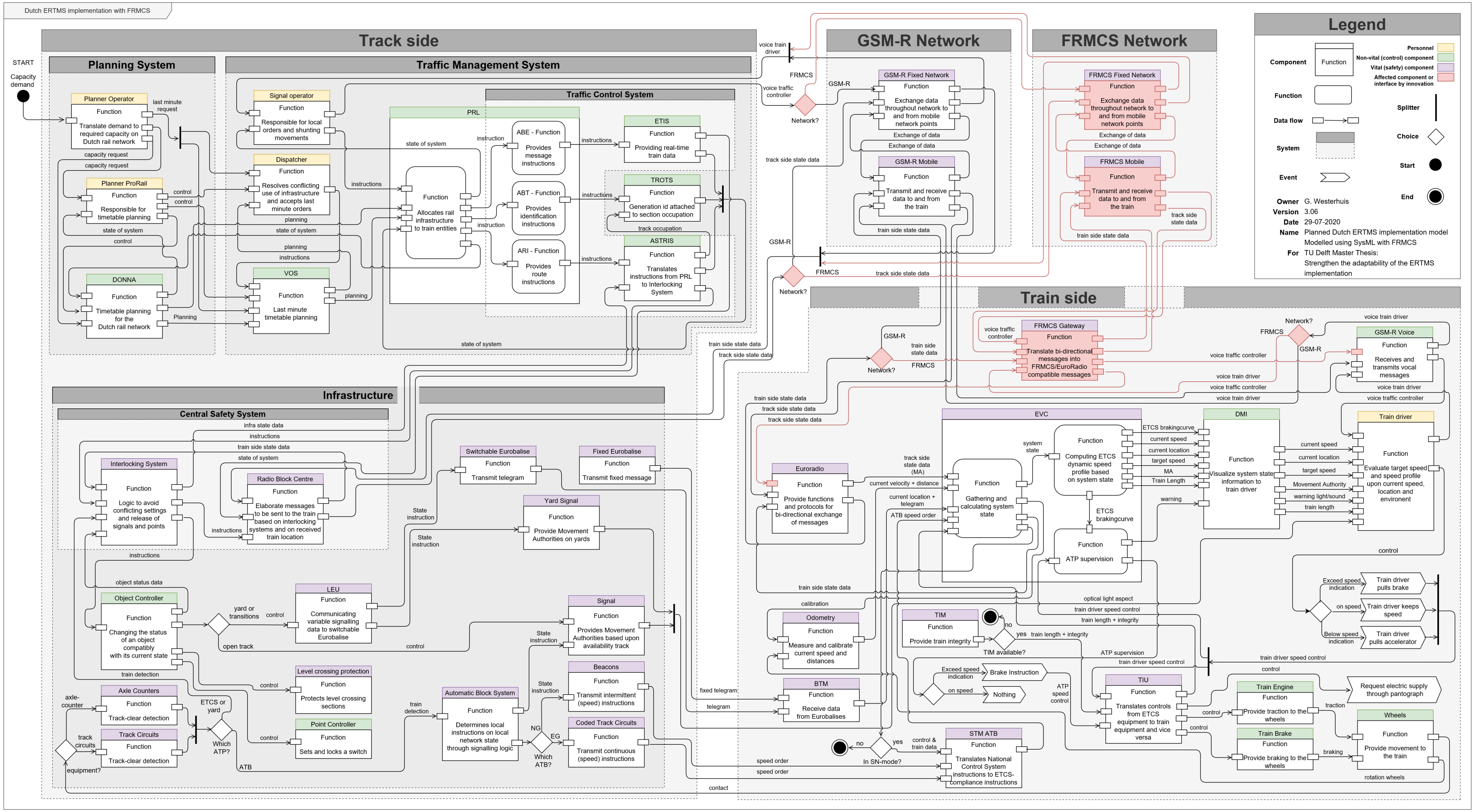

Fig. 4. The Dutch implementation of ERTMS with FRMCS implemented visualized using System Modelling Language.

Connected Driver Advisory System (C-DAS)
A C-DAS is an extension to the general DAS system. A DAS could have several objectives on which it formulates advice to the train driver like scheduling, punctuality, conflict avoiding or energy efficiency. A DAS optimizes the performance of a train as it would if this train is in isolation (Digital Railway, 2019). A C-DAS broadens the input by providing a bi-directional link between the on-board equipment and the TMS. This allows real-time optimisation of multiple trains. However, a C-DAS is but a tool. It relies on the driver to utilize its potential (Leander & Törnblom, 2019). A C-DAS is referred to as ATO with GoA 1. Various challenges must be overcome to utilize a C-DAS. A C-DAS trackside component must be added with an interface to the TMS and through the communication network to a C-DAS on-board component. This on-board component requires a link to the train driver using an additional human machine interface (HMI) to provide its advice. Furthermore, a link is required from the EVC to acquire train state data (Westerhuis, 2020).

Automatic Train Operation (ATO)
Use of ATO enables trains to operate while depending less on train personnel and more on automatic systems. ATO is graded in four grades of automation (GoA) (UITP, 2012). The higher the grade, the higher the dependence on automatic systems. Currently, ATO is usually discussed with GoA 2. This grade requires the driver to close the train doors and operate the train in the event of a disruption. Setting the train in motion, the driving and stopping is automated. Current documentation on ATO over ETCS (such as subset-125 (Bienfait, 2019)) is not officially issued by the ERA yet and is meant only for pilot projects. However, it is expected that the next set of specifications will include ATO GoA 2 (Ruete, 2020). It is disputed if ATO GoA 2 requires more bandwidth than the implemented GSM-R network can provide (Kessell, 2019; Toorn, 2019; Hartwell, 2015; Ricardo, 2019; Fletcher, 2019). Furthermore, the challenges for ATO GoA 2 are almost identical to the challenges for a C-DAS. This means that a trackside ATO must be interfaced with the TMS and have a bi-directional link over the communications network to the ATO on-board (EUG & EULYNX, 2020). The ATO on-board acquires information on the train state through an interface with the EVC (RSSB, 2017). However, unlike a C-DAS, ATO with GoA 2 requires a link to the TIU. Furthermore, Emery (2017) argues that it also could have a large human impact on train drivers with respect to their motivation and skill if their task is reduced to initiate, supervise and potential interfering.

Virtual Coupling (VC)
The last innovation taken into account is VC using vehicle-to-vehicle (V2V) communication. By enabling communication between vehicles, kinematic parameters can be exchanged so that the Movement Authority (MA) can be enhanced with this data (Quaglietta et al., 2020). Trains can be coupled in a similar manner as adaptive cruise control. VC could be extended with a bi-directional interface to the TMS to form train platoons and allow trains to operate at relative braking distances. This utilization of VC is researched in the MOVINGRAIL project (Shift2Rail, 2020). This paper assumes the enhancement of the MA with local train state data. For this, an additional antenna must be inserted to allow V2V communication. The EVC must be able to receive local train state data and form an enhanced MA. For this, every train that is virtually coupled requires a TIM device. Furthermore, the interlocking must be able to set and release points based on coupled trains instead of single trains. However, these functions introduce also challenges for standardisation, interoperability and scalability (Fraga-Lamas et al., 2017). Furthermore, operators must cooperate to allow trains to be coupled for performance optimization. This could be achieved by forming a cooperative consortia (Shift2Rail, 2019).

C. The solutions and their validation

With the identified critical issues and adaptability factors, solutions are proposed that strengthens the adaptability of ERTMS. These solutions are summarised in table III (Westerhuis, 2020). The proposed solutions are validated by three experts with different areas of expertise; an ERTMS expert, the Dutch ERTMS program manager of the Ministry and a legal advisor of the Ministry. The interviews with these experts can be found in the linked master thesis (Westerhuis, 2020). Its validation is done in the context of a use case. The use case simulates the implementation of FRMCS-only on the Kijkhoek - Roosendaal corridor with a necessary update towards the next set of specifications. The ERTMS expert argued that a main shortcoming of the technical solutions is the restraint of the signalling industry to sell components that are prepared for foreseen innovations without official documents. Draft documents are conceived as insufficient. For this reason, he endorsed the solution to establish a modularity between components that are critical for future ERTMS adaptability.

The experts further indicate that there is an absence of the use of the entire range of instruments available to provide a good governance and stakeholder management. Involvement and transparency is endorsed but could prove ineffective when not combined with firm and proper use of instruments such as regulations and obligations. The main endorsement by all three experts is the creation of a comprehensive roadmap that provides information on the various aspects of the Dutch ERTMS implementation. Finally, the interviewed ERTMS expert introduced the negative effect of technical national rules on adaptability in addition of the already specified national values. In other words, an update of the on-board equipment can imply that this equipment must meet various additional, newly established rules of other European countries. This decreases the business case for each update.

TABLE III

PROPOSED SOLUTIONS TO STRENGTHEN ADAPTABILITY OF ERTMS

Technological implementation

Topic	Critical issue	Proposed solution
ERTMS baseline management	ERTMS baseline updates are expected in the future but these standards are until now not fully compatible and experiences maturity issues.	Choose a dominant standard and tender, using small regions and with transparency, with a new standard. This new standard must be considered mature enough and backwards compatibility is ensured.
ETCS application level management	ETCS application levels have an effect on the requirements for necessary track and on-board components.	Transparency is important in choosing the application level. Furthermore, let ETCS HL3 be a sector-wide driven innovation and include it in the official specifications.
Interface management	ERTMS and its interfaces are continuously evolving with changing needs and possibilities.	New interfaces must be enabled through modularity using standardization and facade patterns.
Component management	Required components of upcoming innovations could have overlap or incompatibility between them or with existing components.	Prepare various components for the integration or cooperation with additional components. More information about the specific preparation can be found in the linked master thesis (Westerhuis, 2020)

Governance and stakeholder management

Topic	Critical issue	Proposed solution
Position program ERTMS	The program is sensitive for the interests of a single or a selection of stakeholders.	Balance stakeholder involvement by stimulating a diverse group of employees in the ERTMS program and give the means necessary for the program manager of Min I&W to function as central leader.
Stakeholder involvement	Cooperation and coordination between stakeholders such as involved actors, experts and interest group or end users.	Increase sector-wide support for decisions by involving stakeholders with informal interaction, a comprehensive roadmap, organized meetings and joint KPIs.
Generation of support	Interconnection between stakeholders and support of ERTMS and upcoming innovations.	Improve interconnection and support by appointing ambassadors, organizing meetings and creating visualizations.
Changeability in contract	Decreased changeability due to contract setup or static policies	Preserve adaptability in the contract by rewarding changeability and by preserving flexibility in applicable policies.

Financial and regulatory adaptations

Topic	Critical issue	Proposed solution
Availability of budget	Marginal technological changes are considered expensive.	Acquire sufficient budget to cover necessary marginal technological changes.
Certification	Changing national values result in the necessity to entirely re-certifying vehicles.	Change the certification approach by certifying a vehicle against a range of national values instead of only the applicable value.

D. Adaptability Strategy

The integrated strategy is visualized in figure 5 in the form of a suggested roadmap. This subsection provides further explanation of this strategy in the form of various actions that must be adopted by stakeholders to strengthen the adaptability of ERTMS. To increase technical adaptability, various measures are advised. First, ERTMS baseline management should be clear and transparent. Therefore, select B3R2 as dominant standard with the possibility to update to another set of specifications if maturity and backwards compatibility is ensured and if tendered in small regions. Second, a clear and transparent ETCS application level management should be executed by including stakeholders in the process of implementing ETCS L2 with preparation towards ETCS HL3 and including ETCS HL3 into the official specifications. Third, ERTMS should be implemented to allow interfacing with and integration of components required by upcoming innovations. Adaptability is improved with the establishment of a modular system through standardization and facade patterns.

To increase adaptability with respect to governance and stakeholder management, various measures are advised. First, all roles in the governance model must be properly fulfilled enforced by the firm and proper use of the entire range of regulatory instruments that are available for the Ministry. Second, stakeholders must be involved to increase cooperation and coordination using various methods, but especially with the creation of a comprehensive roadmap that includes plan, status and new innovations. Third, support should be generated with various methods to increase interconnection and reduce the negative effect of arising issues. Fourth, changeability should be inserted in the contract by rewarding instead of penalizing it. To increase adaptability with respect to financial and regulatory aspects, various measures are advised. First, to free sufficient budget to deal with required marginal technological changes. Second, to be aware of the effect that changing national values or national technical rules could have on ETCS on-board equipment.

VI. CONCLUSION

This paper gives meaning to the term adaptability and provides factors that influence it. Furthermore, it identified the meaning of adaptability for ERTMS as it identifies

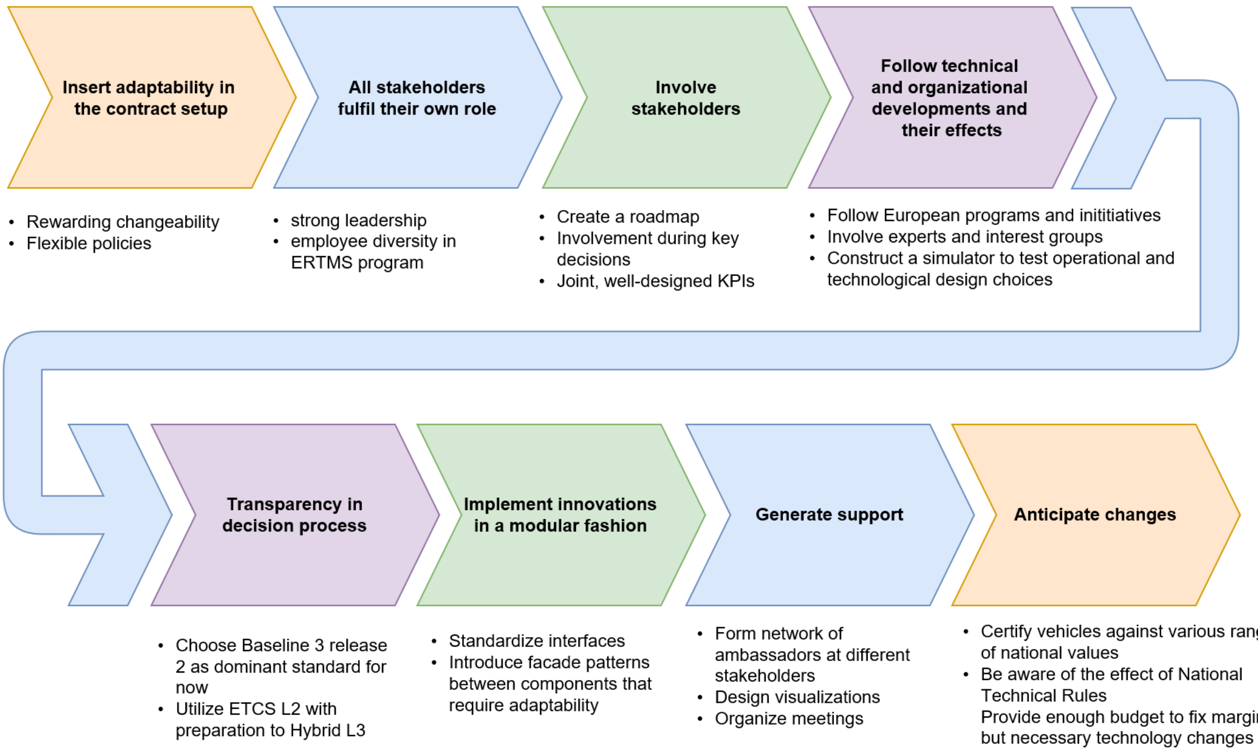

Fig. 5. Suggestion for a roadmap through the integrated strategy to strengthen the adaptability of the ERTMS implementation.

criticalities for future configurations. The main takeaways from this strategy is that a more transparent and clear implementation process is required. The proposed actions are involvement of stakeholders with key decisions and updating stakeholders of the implementation through a comprehensive roadmap. This roadmap must provide clarity and legal certainty necessary for stakeholders. Furthermore, flexibility should be maintained by introducing technological modularity through standardisation and facade patterns and by rewarding changeability through the contract setup.

As ERTMS is a complex and continuously evolving system, the provided strategy could prove ineffective if unforeseen developments occur. It is necessary, in time, to perform further research if the used sources are still viable and applicable for that scenario. Research is recommended in the creation of a roadmap. This must be a comprehensive roadmap that provides information on the planning, status, upcoming innovations and their effects. This roadmap must also describe overlap and synergies between these innovations. While this paper discusses the effects, it did not produce a plan and timeline for upcoming developments. Further research is required on the detailed effects on interfaces and components by implementation of upcoming innovations discussed in this paper. The described effects are based on documentation and architectures that are not yet officially established or proven. The various design considerations for each innovation could differ in the future or in practice. Further research is needed on the effect of national values and national technical rules on adaptability of ERTMS. This paper only touched lightly on the issue that changing national values or national technical rules could have on ETCS on-board equipment that operates in multiple European countries.

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Appendix B – Methodology steps

In this appendix, the various steps are explained in further detail. In Figure 26, the steps are visualized.

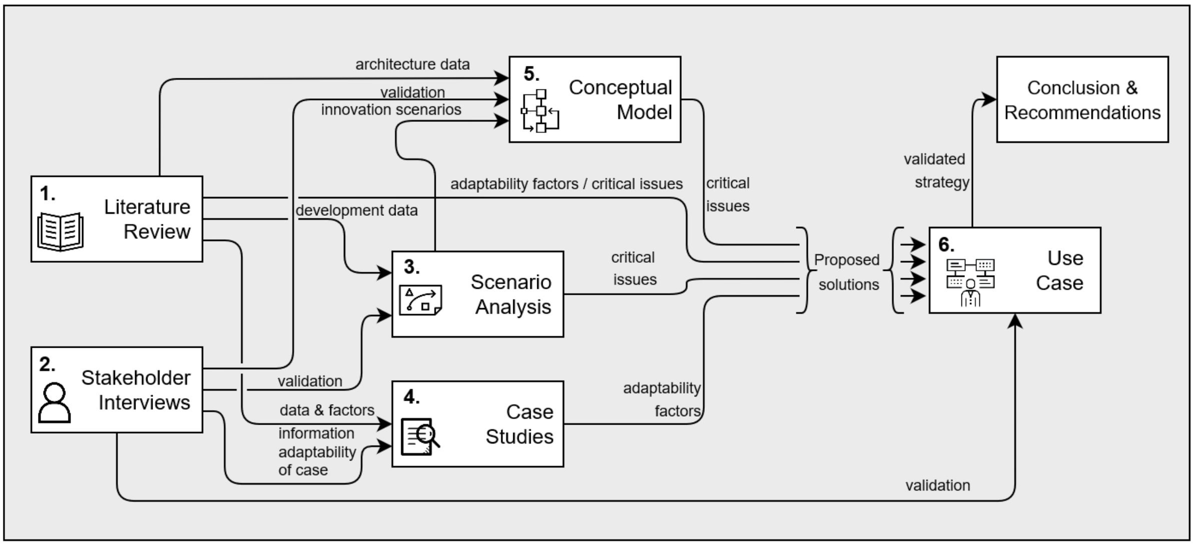

Figure 26: The six steps visualized

Step 1 – Literature review

The literature review provides factors that influence adaptability. Besides this goal, the literature review is the base for the other analyses. It provides information about the basics of ERTMS such as: a general description, its innovations, its Dutch migration process and the migration processes in other European countries. Furthermore, it will provide information about the three case studies. The literature review is carried out in chapter 2.

Step 2 – Stakeholder interviews

The stakeholder interviews provides data where the literature review proves to have inadequate information for the required goal. The stakeholder interviews will provide further information about ERTMS, its Dutch implementation and potential challenging trends of ERTMS applicability in the future. The stakeholder interviews also provides information on the three case studies and its factors that proved to be hindering or stimulating adaptability in the project. Finally, the use case and its adaptability to the FRMCS implementation is validated with three experts through interviews. The interviews are listed in appendix F.

Step 3 – Scenario analysis

By analysing various probable future scenarios, challenging trends within the ERTMS applicability of the Dutch implementation of ERTMS are identified. Using the literature review and the stakeholder interviews, various probable scenarios are generated. Scenarios which imply that certain developments take place. By analysing these developments, critical issues are identified that influence the adaptability of the Dutch implementation of ERTMS. This step is carried out in chapter 3 and 4.

Step 4 – Case studies

Three case studies are carried out to confirm adaptability factors identified in the literature review in real-world examples. By evaluating these projects, lessons can be learned for the adaptability of the implementation of ERTMS. These lessons are translated into adaptability factors. The three cases are as follows:

- The HSL-Zuid project
- The implementation of RouteLint
- The implementation of the Dutch Smart Travel Card (OV-Chipcard)

This step is carried out in chapter 5.

Step 5 – Conceptual modelling

To assess the effect of the gathered scenarios in step 3, the Dutch ERTMS system is mapped using a conceptual model which visualized data input, output and processes. This is done in chapter 4. When parts of ERTMS change or interfaces are added, these can be inserted into the model and thus provide insight its effects. These are identified as critical factors for ERTMS applicability towards the future. These insights can be used to propose countermeasures to improve adaptability of ERTMS. The models are visualized in Figure 10 to Figure 19. The semi-formal method chosen to visualize this is SysML (System Modelling Language). SysML facilitates abstractions to manage size and complexity and is able to detect errors early in system development, which is useful for a complex process like the implementation of ERTMS (SysML, n.d.; Ferlin et al., 2016). This step is executed in chapter 6.

Step 6 – Use case

In order to test and validate the effect of the formed solutions, a use case is introduced. This use case is based upon a corridor which was constructed using the adapted ERTMS implementation according to the solutions. On this corridor with its corresponding environment, a metaphorical development is simulated based on a probable scenario. In this thought experiment, effects of this development and the inability for the system to adapt to it are deducted and thusly the effect of the adapted ERTMS implementation is assessed. This thought experiment is validated by various experts. The outcome is added to the conclusion in the form of additional advice and comments to the integrated strategy. This step is executed in chapter 7.

Appendix C – ETCS application levels

In this appendix, the various ETCS application levels are further explained. It starts with the conventional application levels specified in the TSI Subset-026 (ERA, 2016). After which two used variations are explained: ETCS L1 Limited Supervision (LS) and ETCS Hybrid Level 3.

- ETCS level 1 without infill (see Figure 27)
  By using this application level, ETCS is set as an intermittent ATP system with continuous supervision. The movement authorities are generated trackside and are transmitted at discrete locations using Eurobalises. These standardised beacons are located at specific locations on the track. The train detection and integrity is performed by trackside equipment in the form of track circuits or axle counters. Lineside electronic units (LEUs) are constructed alongside the track to translate data between the signal and the Eurobalise.

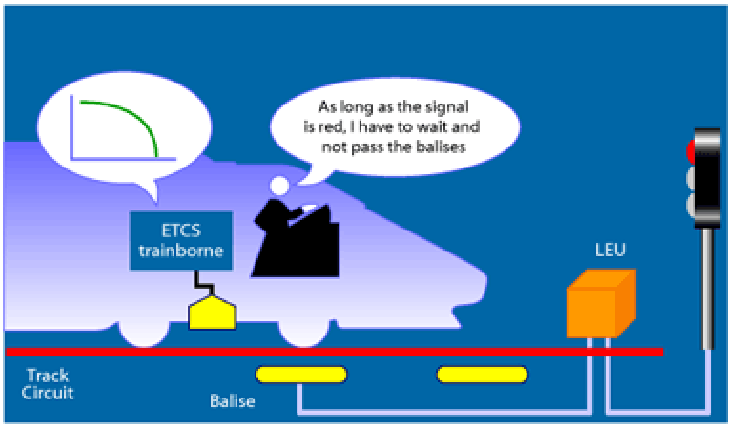

Figure 27: ERTMS/ECTS application level 1 without infill (ERTMS, 2020)

- ETCS level 1 with infill transmission (see Figure 28)
  This application level is similar to the previous described application level. However, the train driver will receive information about coming signals on more frequent basis using additional Eurobalises (infill balises), a Euroloop or radio infill. A Euroloop or radio infill allow data to be transmitted continuously, thus the train driver can anticipate better on a coming situation.

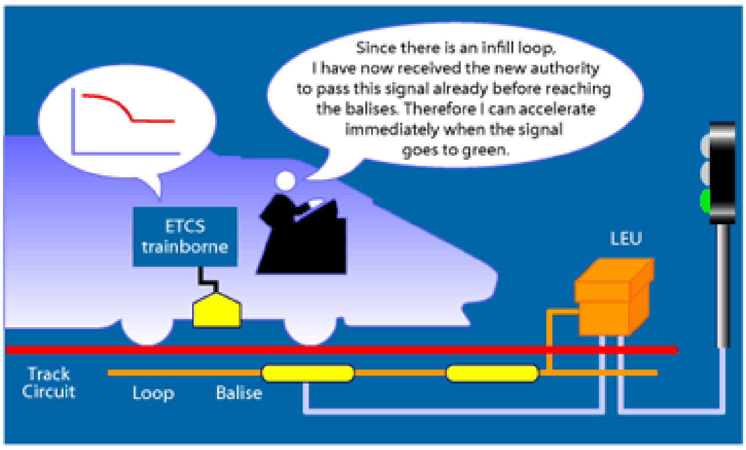

Figure 28: ERTMS/ECTS application level 1 with infill (ERTMS, 2020)

- <u>ETCS level 2 (See Figure 29)</u>
  This level uses data from a Radio Block Centre (RBC) that is continuously transmitted through the GSM-R network instead of intermittent transmitting of data using Eurobalises. Thus, according to the specifications, trackside signals are optional. All information is provided to the train driver using the ETCS Driver Machine Interface (DMI). Train detection and train integrity are still being performed by trackside equipment in the form of track circuits or axle counters. The Eurobalises are mainly used to calibrate the position of the train. This means that the Eurobalise can transmit a fixed message.

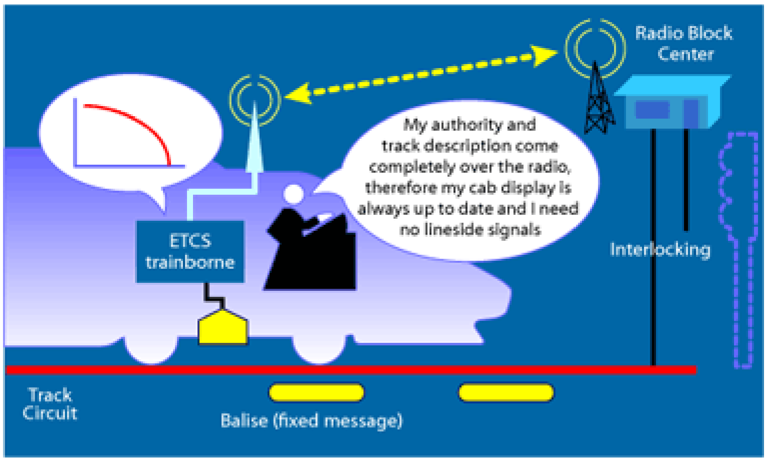

Figure 29: ECTS application level 2 (ERTMS, 2020)

- <u>ETCS level 3 (See Figure 30)</u>
  As with application level 2, ETCS application level 3 is a continuous ATP system. However, this application level uses the on-board equipment to provide train integrity monitoring instead of using trackside equipment like track circuits or axle counters. The module that provides this function is called a TIM system (Train Integrity Monitoring). This module ensures that the trainset is not split accidentally. The position is reported to the RBC. This allows the determination of block occupation by the RBC. The Eurobalises are still required to calibrate the location.

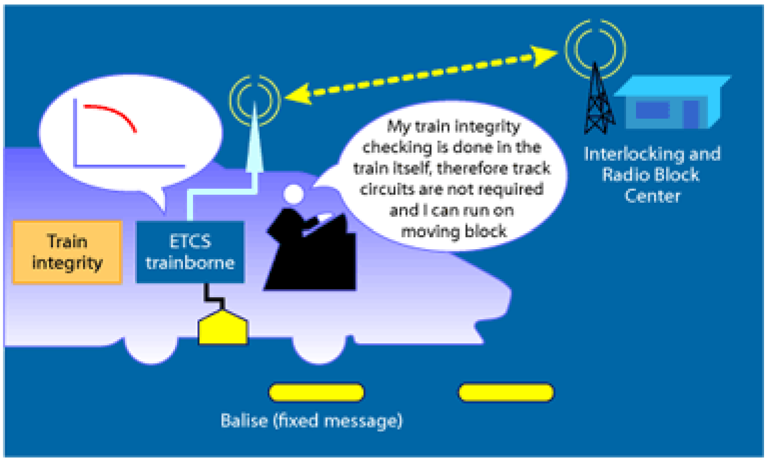

Figure 30: ECTS application level 3 (ERTMS, 2020)

- ETCS level 1 Limited Supervision
  While ETCS L1 as described earlier provides full supervision with every signal. ETCS L1 Limited Supervision is a variant of ETCS with lower cost. Operating using this variant allow trains to be operational with only a part of the lineside signals (ERA, 2016). Supervision is then performed in the background while the train driver still operates using the MA provided by the lineside signals (Stamm, 2012). While this configuration is also possible for L2 and L3, it is only implemented in practice for L1. For instance in parts of Switzerland and Belgium (Hänni & Zurflüh, 2017; Infrabel, 2016).

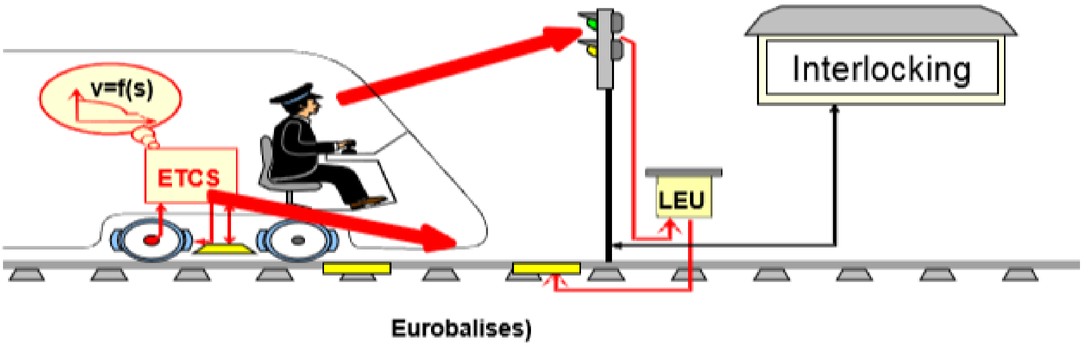

Figure 31:ETCS L1 with Limited Supervision (Stamm, 2012)

- ETCS Hybrid Level 3 (Figure 32)
  An extensive description of ETCS HL3 can be found in section 4.2.1. ETCS Hybrid Level 3, is a hybrid combination between ETCS L2 and L3. Operation in HL3 allows the utilization of the TIM system and therefore reducing trackside equipment and improvement of performance (Furness et al., 2017). However, not every train is required to provide train integrity with on-board equipment. Trains that rely on trackside equipment to provide train integrity, such as track circuits and axle counters, are allowed on the track. These systems are still operational. This allows the use of fixed virtual blocks for trains that operate with TIMs (EUG, 2018).

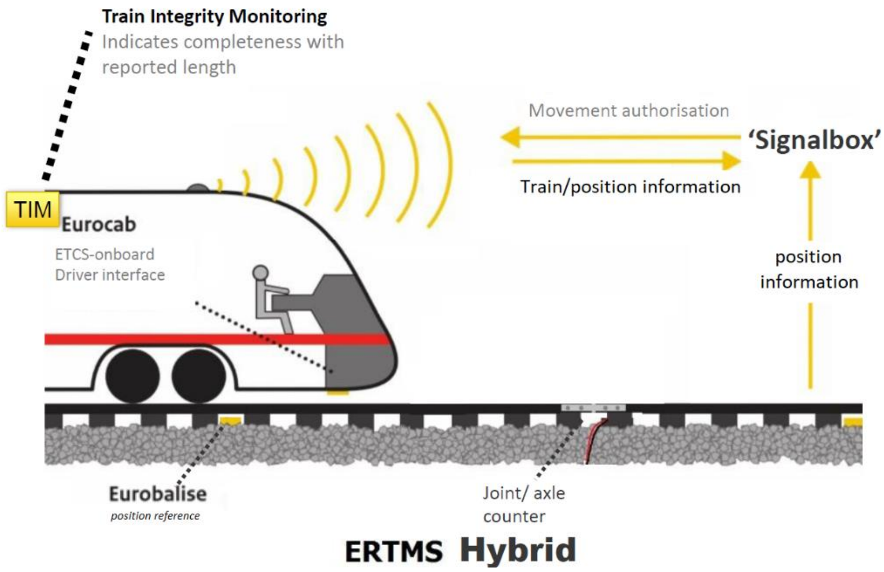

Figure 32: Hybrid Level 3 concept (Bartholomeus, Lecture: ERTMS Hybrid Level 3, 2020)

Appendix D – Stakeholders

This appendix gives a description of the mentioned stakeholder categories and their interests (section 3.5.2). These categories are; the program partners, the train owners and operators, decentralized authorities, port authorities, traveller organisations, infrastructure managers, market parties, users and international stakeholders as mentioned in the program decision (Programma ERTMS, 2019).

Program partners

The partners that established the Dutch ERTMS program in 2014 are NS, ProRail and the Ministry of Infrastructure and Water Management. From 2019 regional and freight operators are partners of the program. These stakeholders set the interface between technicalities and the operational processes. Furthermore, these partners are responsible for acquiring and implementing constraints and requirements from stakeholders. The interests of these parties are different from each other. The Ministry desires a cost-efficient migration with minimal hindrance for travellers and shippers (Min I&W, 2019). ProRail would like to minimize trackside equipment while maintaining safe operations and thus decreasing costs (appendix F.1). NS would like to maintain a controlled migration towards ERTMS, thus wanting the retrofitting and upgrading of their equipment before the roll-out on the infrastructure (Wever, 2016).

Train owners and operators

The train owners and operators have a high interest in the deployment of ERTMS. This category consist of passenger and freight carriers, leasing companies, railway contractors and historical rail transport companies. Generally, these stakeholders want a controlled migration to ERTMS with minimal financial and operational hindrance. Especially the implementation of, or the retrofitting to ERTMS baseline 3 into their rolling stock is a critical process. Various freight carriers have implemented ERTMS baseline 2 into their rolling stock to operate on the Dutch freight corridor (the Betuweroute). At that time it was unforeseen that these trains must be upgraded further to operate on the planned national rail network which require replacement of software and hardware. The freight carriers demand subsidy for this development according to freight rail interest group RailGood (SpoorPro, 2018, 2020).

Decentralized authorities

Provinces and municipalities would like to acquire the benefits of ERTMS on their own regional corridors. For example, while the planned Dutch ERTMS implementation does not directly provide support for ATO, the province of Groningen with regional train operator Arriva would like to operate with ATO as soon as possible (SpoorPro, 2020; Provincie Groningen, 2020).

Port authority

Port authorities Rotterdam, Amsterdam, North Sea Port and Moerdijk see the expansion of the number of ERTMS freight corridors as an opportunity. To ensure their growth, port authorities would like to help bring about a modal shift from road to rail. The Port of Rotterdam Authority set a goal to increase hinterland rail transport from the current 11% to 20% in the year 2035 (Port of Rotterdam, 2019). This goal is strongly linked to the interests from freight carriers.

Traveller organisations

Traveller organizations are positive about the migration towards ERTMS and see it as opportunity to improve on accessibility throughout the Netherlands. They would like to maximize the benefits for the traveller by improving the attractiveness of rail transport. These organizations would like to see a modal shift from car use to other modes, such as public transport (Bos, 2019).

Infrastructure managers

Various tracks are managed by different parties than ProRail. These IMs would like to preserve a good connection to the main network without problematic operational transitions for their (shunting) locomotives. A large IM besides ProRail in the Netherlands is Strukton Rail Short Line. They want to guarantee rail availability to their clients (Strukton, 2020).

Market parties

ERTMS suppliers, engineering and constructing companies should make their expertise and abilities clear such that a realistic program can be formed and these experts can be utilized in an optimal manner. Which is beneficial for all parties. Furthermore, requesting parties should be clear in their request to the market. This proved to be difficult in examples from the past, like the HSL-Zuid (section 5.1).

Users

The implementation of ERTMS requires changes in various processes throughout the rail sector. In total of 180 different roles and functions (in the Netherlands this corresponds to 15,000+ users) must acquire training to get accustomed to this new development (Programma ERTMS, 2019). Mainly the tasks of train drivers, signal operators and dispatchers are affected. The effect can be seen in the constructed conceptual model in section 4.1.2.

International stakeholders

Various international authorities, such as the governments of Germany and Belgian, have an interest in the Dutch ERTMS implementation with its corresponding choices. Due to the interoperable nature and goal of the European ERTMS implementation it is important to inform international stakeholders systematically. However, because it is a rather unknown and unpredictable process lessons should be exchanged between responsible authorities of different European countries.

Appendix E – FRMCS migration strategies

This appendix provides evidence for the statement given in section 4.2.3 where principle solution B was preferred above the other two solutions due to its limited impact. As seen by assessing the number of red components and interfaces in Figure 33, solution C has the largest effect on the implementation. While solution A does not touch the EVC/Euroradio, it does require the interface between the Euroradio and the GSM-R network to be relinked. With solution B this is not the case. With this solution, both network systems can be processed by the Euroradio for the EVC to interpret the message. With this, solution B is preferred.

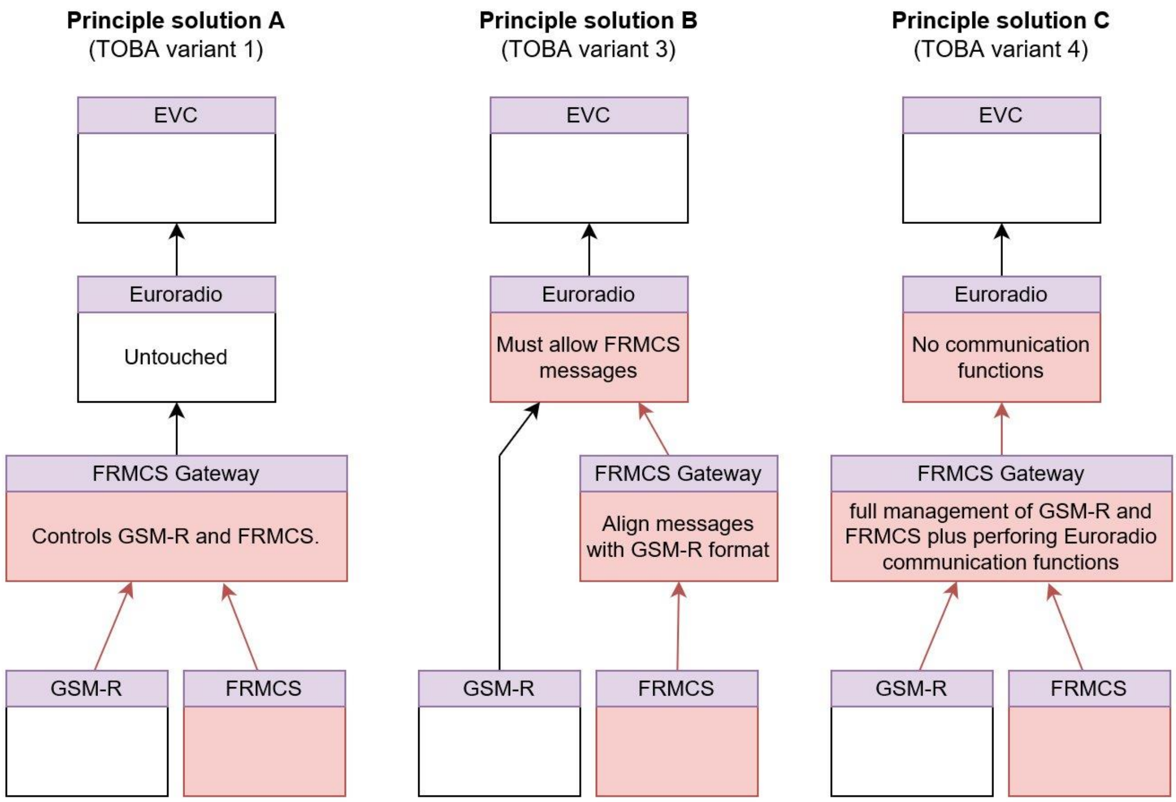

Figure 33: Exercise impact on ERTMS implemented based on migration strategies proposed by EIM (2019).

Appendix F – Respondents scheme and interviews

This appendix provides an overview of the respondents interviewed throughout the research process (Table 25). Each respondent gave their interview on personal title instead as representative of the corresponding company. Furthermore, each interview is validated by the respondent itself to ensure that the different described passages are in compliance with the facts or their personal opinions.

Table 25: List of respondents

App	Name	Company	(Former) function	Subject
F.1	Maarten Bartholomeus	ProRail	ERTMS expert	ERTMS
F.2	Frank Ruessink	ProRail	Application architect	ProRail ICT
F.3	Alfons Schaafsma	ProRail	Advisor traffic management	ProRail VL
F.4	Peter Wilms	Independent	Rail advisor	ERTMS in Europe
F.5	Bob Janssen	EULYNX	Data architect	ERTMS & EULYNX
F.6	Jan Tiecken	ProRail	Contract management	HSL-Zuid
F.7	Ed Visser &	Infraspeed	Operations manager	HSL-Zuid
F.7	Aad Hertogs	Infraspeed	Maintenance engineer	HSL-Zuid
F.8	Arnold Hornung	Infraspeed	General manager	HSL-Zuid
F.9	Gérard Hoeberigs	Min I&W	Policy advisor	HSL-Zuid
F.10	Jan Tiecken	ProRail	Contract management	HSL-Zuid
F.11	Jelle van Luipen	ProRail	Program manager innovation	RouteLint
F.12	Johanna Knijff	ProRail	Implementation manager	RouteLint
F.13	Ramon Lentink	NS	Implementation manager	RouteLint
F.14	Madeleine Schellaars	NS	Implementation manager	RouteLint
F.15	Anonymous	Translink	Manager	OV-Chipcard
F.16	Niek Govers	Connexxion	Integration architect	OV-Chipcard
F.17	Erik Voltman	NS	Contract manager	OV-Chipcard
F.18	Marco Kartman	Translink	Business innovator	OV-Chipcard
F.19	Ernst Cramer	NS	Stakeholder management	Position ERTMS
F.20	Hugo Thomassen	Min I&W	Program manager ERTMS	Position ERTMS
F.21	Merel Remkes	Min I&W	Program manager ERTMS	Use Case
F.22	Atsert Walsweer	Min I&W	Legal Advisor	Use Case
F.23	Daan Kers	Ricardo	ERTMS expert	Use Case

Appendix F.1 – Interview Maarten Bartholomeus on ERTMS (Summary)

Subject	ERTMS implementation
Respondent	Maarten Bartholomeus
Function	Expert ERTMS/ETCS
Date of interview	07 April 2020
Date of verification	22 April 2020
Location	By phone

Important notions of the interview

- Due to the nature of the ERA specifications, with their focus on train side equipment, the track side equipment is not specified allowing flexibility and versatility. A drawback is that it is not an unambiguous standard and rather complex throughout Europe.
- The harmonization of operational processes is more difficult than of the technology.
- Innovating is difficult if this component operates within SIL-4 requirements.
- Various hardware and software components are currently integrated making innovating expensive and time consuming.
- FRMCS will be introduced to be backwards compatibility with GSMR.
- Hybrid Level 3 can be utilized according to the current planned Dutch ERTMS implementation. Regarding the passenger trains are TIMs within the program scope.
- 3kV has little to no effect on the ERTMS implementation.
- The benefits of virtual coupling are not entirely clear.
- The interlocking and Radio Block Centre handled as an integrated system within the program.

How does ERTMS work?

ERTMS is interoperable safety system specified by the ERA. The most important part of the specification is the language (messages) and the ERTMS on-board unit. The infrastructure manager must feed it messages which it will understand. The form and transmission of these messages are also specified in the European specifications. If the infrastructure manager works within this form and use the standard transmission medium (GSM-R), then interoperability between countries can be ensured. Furthermore, it should ensure that train and trackside are independently operable. How the trackside generates these ERTMS messages is not specified. The original thought was to design also the trackside and train components in a modular fashion. However, this was deemed too complex in the ’90 by the manufacturing industry. The European commission put the focus for the ERTMS specification on the interoperability between train and track.

Originally we have started with three independent projects, Amsterdam-Utrecht, the Betuweroute and the HSL-Zuid. For each we have provided the specifications to suppliers of trackside equipment, but for each corridor we have received entirely different systems. The ERTMS specifications is focused on the interoperability and for this the trainside, without taking trackside much into account. The reason for this is due to the various preferences of the countries in Europe, each desiring different functions in their ERTMS trackside system. That makes ERTMS a flexible and versatile system, but rather complex throughout Europe.

How are stakeholders aligned throughout the process?

Formerly before the infra manager and train operators were split. NS was responsible for both trackside and train systems and operation. The developments were discussed internally and agreed with the ministry. However, nowadays this is not the case anymore. Because of the split of the organization and responsibility (and budgets) changes to the system have become more complex. There is no centralized leader that organizes the process and makes larger decisions. The Ministry of Infrastructure and Water Management is the end responsible but they do not have the corresponding knowledge. The ERA is too high level for such a task, they would not like to be responsible for the safety of the actual ERTMS implementations.

In the implementation of ERTMS, the harmonization of the technology is much easier than the harmonization of the operational processes. The rail sector consists of highly knowledgeable people that know exactly what they do, however they are not that flexible when considering new technology and adapting existing procedures. Also note that the first and utter priority of the railways is the safe, reliable and robust operation. Changes to these processes are often regarded as treats.

How is the implementation in Europe organized?

As the ERA-ERTMS specification does not specify the trackside components the required system behaviour is specified for the Dutch rail infrastructure systems. Regarding the trackside specification there is no European process standardisation process, several attempts are made but the wait and see attitude of larger European countries does not help. The Dutch specification of the trackside ERTMS systems will not to cause interoperability problems. It however may not reduce the cost for trackside systems as these are not standardised but this was of course necessary to implement ERTMS.

In 2022, a new TSI will be made available. To achieve a more cost efficient implementation a higher level of standardisation and modularity is subject of discussion.

The coupling of hardware and software and SIL

The technological innovation mentioned in your thesis are also the developments that I see. The difficult thing about technological innovations is that these innovations also change the way organizational processes are conducted. This is the most difficult part and is likely to cause the most problems. However, the technological part in innovations is also difficult. Especially the current integration of software to hardware, which was done for safety reasons. Many components in the rail sector operates within SIL-4 (Safety Integrity Level). This is the most strict safety level. Another a drawback is the coupling between hardware and software of most (older) safety products, this is not a very adaptable solution for the implementation of new innovations. However, in the latest developments, this uncoupling is much more the trend.

An example is GSM-R. This was integrated into the ERTMS on-board safety components which makes it difficult to change. This is a problem due to the fact that GSM-R is a dated technology. However, recent developments show an uncoupling of systems which makes it more adaptable to new technology. This is increased in GPRS (General Packet Radio Service) and further elaborated in FRMCS.

Current updates, due to this coupling are rather expensive. This is not simply an update, but the update must be evaluated on SIL-4 safety and hardware components that are made and maintained by specific suppliers cannot be delivered on short notice.

New innovations

ERTMS seems to be a good enabler for new technologies. The operational benefits of ATO are for the train operation more obvious than those of ERTMS. ATO can also help the train driver to drive on braking curves instead of the earlier operational processes (optical signals). The benefit of ATO with GoA 2 over an SIL-4 ATP system with full brake curve supervision is that the developments can be researched within a SIL-0 system. This makes developing ATO systems and operationally much easier. There have been various tests already performed and ATO is already operational in the UK. It is true that the specifications ATO over ETCS are not officially released. However, 95% of the specifications are already made. GSM-R would provide enough bandwidth for ATO GoA 2. For GOA3/4 more bandwidth is required (possible camera and other information exchange).

GSM-R is a dated system which transmits data throughout the system using seconds. Currently, this is sufficient. But with the increasing complexity in the rail sector, this is too slow. Thus, the migration towards FRMCS is required. Besides, FRMCS will be introduced in ERTMS in a way to support backwards compatibility to GSM-R.

Hybrid Level 3 is an improvement which can optimize the planned Dutch ERTMS implementation. It is a robust solution that maximizes capacity and minimizes infrastructure equipment and thus cost. An useable version of the original Level 3, in which no trackside train detection was foreseen is not solvable/robust within the Netherlands. This is due to the complexity of the Dutch rail network. The trackside (and dispatcher) would be blind for trains without connection. Both for short interruptions in trains, in the communication network or because of processes like shunting. Without a fallback train detection no safe operation would be possible, i.e. too big of an impact on our high performance network. This makes HL3 combines both worlds, (trackside train detection and train position reporting, delivering a good cost effective, robust and high capacity solution.

3kV is also an improvement for faster acceleration and capacity. The change towards 3kV is not problematic for the ERTMS implementation. These are not national values but configurable values on the trackside and the trainside. Trackside must transmit the state of the traction system to the train and the train must know that it can handle this voltage. The most complex transition is the actual pantograph trainside and the actual voltage change plus any necessary voltage locks trackside, but this is outside the scope of the ERTMS implementation. The transmission/voltage change over locations to let the train know what voltage the system shall operate in is transmitted through the RBC.

The reason for virtual coupling is not clear. This is for two reasons. The first reason is that for virtual coupling the first train would have to slow down in order for the coupling. But when is that necessary? The second reason is, if the trains are required to separate to different corridors, the track change system requires time to set its switch. As this process is not fail safe the absolute brake distance would be required again. So the distance between trains need to increase dramatically before such an interchange. On the long term, if the speed of trains is increasing, it might be helpful. Also if you implement fail-safe switch operation, it could be more beneficial.

Discussion SysML

The model has been updated with discussion in mind

Some important notions during discussion

- The SysML model of ERTMS/ETCS application level 2 is identical to application (hybrid) level 3. There is no train software difference between these levels apart from the potential implementation of the TIM.
- TIMs for passenger trains are part of the current ERTMS implementation program
    - The function of the TIM is in level 2 or Level 3 identical. It provides data to the EVC if the train with the train length is still complete. The EVC forwards this to the trackside with the standard position reports (both in L2 and L3). It has no input from other specified components in the sysML model.
    - This message this EVC generates with the TIM info is thus identical between both levels. Also are all other train functions regarding braking, DMI and such identical for Level 2 and Level 3.
- The interlocking and the Radio Block Centre is provided together in the program. ProRail calls it the CSS (Central Safety System).
- The PRL allocates trains as entities to certain sections and requests train paths/routes from the trackside safety system corresponding the planning.

Appendix F.2 – Interview Frank Ruessink on ProRail ICT (Summary)

Subject	ProRail ICT
Respondent	Frank Ruessink
Function	Application Architect of ProRail ICT
Date of interview	28 April 2020
Date of verification	30 April 2020
Location	By phone

Important notions of the interview

- ERTMS does not have a large impact on the ProRail planning systems and TROTS. An initiative, the PEIL project, has been setup to regulate changes in logistical systems due to the ERTMS implementation (PRL, ASTRIS and new application ETIS). ERTMS provides more data that can be utilized by the traffic controller through ETIS (examples are: current speed, number of axles, axle load and type of train). ETIS, in turn, can send messages to trainside equipment (for example to enable the transition from standby(SB) to staff Responsible(SR) mode without using the override function)
- No issues are foreseen in adapting the ProRail ICT systems to the planned ERTMS implementation. This is mostly due to the modular setup of ETIS. Newer baselines can be installed with additional translation modules.
- ProRail ICT is going to work with the split functionalities (IXL and RBC) of the CSS with interfaces towards ICT systems. The integration of these components into one system inquiry are part of freedom of design by suppliers.
- EULYNX is an initiative to standardize interfaces between signalling system components. ProRail still maintains their own interfaces in their ICT systems. If EULYNX becomes more of a success in European countries with regard to interfaces to the ICT systems, then ProRail may decide to go along with this development.
- The sysML model, with respect to the TMS and TCS, is according to the current ProRail ICT systems. However, you can add VOS and TROTS.

What the connection between ProRail ICT and ERTMS?

You have the PEIL project (ProRail ERTMS ICT Logistiek). This project checks and regulates the changes in the logistical systems which are required when implementing ERTMS. That any new required instructions can actually be provided by these systems. The PEIL project also focusses on the planning systems, however current developments on ERTMS don’t have a large impact on these systems. Our current planning systems are DONNA and VOS (Verkeersleiding Ondersteunend Systeem). The logistical systems which have a focus of PEIL are PRL, ASTRIS and a new application ETIS.

Require these systems a change due to the ERTMS implementation?

Yes, ERTMS provides more data. This data can be made available to the train traffic controller. One of the functionalities which is long desired is to check if a train is stationary or not. With the current track circuits or axle counters, this is not possible. One of the reasons to create the application ETIS is to provide this data to the train traffic controller. Furthermore, ETIS provides general train data, like number of axles, axle load and type of train (passenger or freight).

Do you have concerns about the adaptability of the ProRail ICT systems?

With the current ATB system you let a train driver and conductor know through signals and lights on the station when to depart or not. With ERTMS, this authorization is through the cab. However, if the train does not know its location, then the RBC is not able to generate an authorization for that train. If this is the case, a message is transmitted that the train is enabled to operate in staff responsible mode, thus enabling the train to move without the driver having to override the protection system. This is not a specific adaptability issue, but more a consequence to the functionality of ERTMS that such type of message must be added to the process. An accurate GPS location detection system in the train connected to the on-board could solve this problem.

I see no issues for adaptability of the ProRail ICT systems in the future. ETIS follows all messages transmitted between the train and RBC. We have specified that the RBC must add the version number to the message so that the ICT systems can translate these messages accordingly. ETIS has a rather modular setup. This means that if a newer baselines is released it requires only an additional translation module being implemented. ETIS in itself does not have to change. We tried to keep ETIS from being too dependent on the form of the message.

The Interlocking and Radio Block Centre is integrated in the current ERTMS program, does that give any problems to adaptability?

The function of the RBC stays the same as the ERTMS air gap is standardised. ETIS is constructed on this fact. The control of switches is a function of the interlocking system. While this is requested as a total system (Central Safety System), technically it is specified with two interfaces for these two different functions.

There are current interlocking systems that are based on legacy systems or older versions of ERTMS. We want to keep ASTRIS in communication to the interlocking to provide a good stable environment for the PRL to work in. A new development is that axle counters were introduced as trackside train detection. Resetting axle counters requires a new instruction for ASTRIS to handle this scenario.

EULYNX is an initiative, driven by IMs, where communication between components is standardised. For instance the communication between the CSS and the object controllers. This program wants to standardize other interfaces as well, like the link between the CSS and TCS. ProRail does not (yet) adopt the specified interfaces between CSS and the TCS and still makes use of own developed interfaces. If, in time, it becomes clear that EULYNX is a success and that multiple European countries adopt this standard and that suppliers also adopt this in their products, then ProRail might need to take a step to this program. Thus replacing ProRail interfaces with EULYNX interfaces. This moment, it is still unclear if suppliers adopt to this initiative.

Why is this standardisation required?

Currently, when ERTMS is implemented trackside, one supplier is chosen to construct and maintain this. However, ideally switches and object controllers for instance are operable which each other independent to which supplier these delivered (bombardier, Siemens or Alstom). Currently, these parts were coupled in such a way that a single supplier can work with these components. Thus forcing IMs to work with a single supplier on a specific corridor. We want a USB-like similar concept.

Does the CSS have a prescribed structure?

The interface between the interlocking and RBC is not prescribed by ProRail. This must be a supplier freedom. Furthermore, if you would specify this interface further, then you possibly would exclude suppliers. The safety system (CSS) is requested to the market as total system and the supplier should be free to construct this CSS in their own style.

ProRail ICT still works with the split functionalities as defined in the ERA specifications. For instance, on the Betuweroute, you have an unequal number of IXLs and RBCs. If you define this as CSS systems, then where would the boundary of these systems be? If, on a corridor, the RBC and IXL are integrated into CSSs, then these systems must have clear area boundaries. In practice this might prove difficult. So, we still work with two interfaces: one towards IXL and one towards RBC.

However, what if the IXL will change in the future? Or even be removed due to various innovations like ERTMS/ETCS level 3 or vehicle-to-vehicle communication?

Even if trains generate their own MA's, there must be a parent planning. Also the traveller must know when a train arrives or not. Otherwise, trains must depart with such high frequency that travellers just can go to a certain platform, like metro. Besides, I do not see the benefit of virtual coupling due to long braking characteristics and its unpredictability. Why couple virtual when a train can be coupled physically? So I do not see it happen that trains drive within relative braking distance. Furthermore, rail switches require time to switch position and this may fail. For this reason the profit of a train that is able to closely follow it predecessor is marginal. I am not a believer of high capacity gains in using pure level 3. Because you fully rely on train integrity by train equipment. For instance, if you start the system with track circuits, you know that a track is occupied. This is already different with axle counters. But with integrity generated by the train itself, if you start the system, you know nothing yet.

With axle counters you must first "sweep" a section (ride on the entire length of a section). This sweeping makes sure that nothing is on the track. If you fully rely on on-board TIMs and you lost a train, operations must be stopped. Then you must sweep an entire area before operations can return to normal. It is inevitable that systems experience occasional downtime.

Theoretically, you should have equal capacity with level 3 and level 2 if you decrease block size enough and position the sections right. The benefit of hybrid level 3 is only useful for departing trains to quickly release a platform track but further gains are marginal to me. Although trains can drive closer together on open track, they must go through the same rail switch at the end of the track and thus the second train must retain enough distance to allow time for the switch to be operated and detected in the correct position. For this the train is required to drive on braking distance. Due to this, the benefits are lost.

Level 3 would be beneficial in a large railway network which is spread thinly, for instance Finland. Level 3 would decrease trackside equipment dramatically and thus increase cost efficiency.

What would be the consequence of integration of ATO and the TMS system?

Currently, the only communication between track and trainside is through the safety system. The exception are the telephone calls between traffic controller and train driver, this is however a tedious process. With the current state, you miss a certain logistical tuning between controller and driver. This would increase economic efficiency and departure, passage and arrival accuracy. We do have safety tuning, such as maximum speed and movement authority.

I expect that ATO will increase the smoothness of operation and capacity on the rail network more than the step from level 2 to level 3 or hybrid level 3.

Discussion SysML

The model has been updated with discussion in mind

Some important notions during discussion

- The current structure of the TMS and TCS system looks right
- PRL contains a part management and a part of train control of ETIS and ASTRIS. We would like to separate this more in the future.
- VOS (Verkeersleiding Ondersteunend Systeem) must be added.
    - DONNA is a system which composes a planning up to 36 hours beforehand.
    - VOS can adjust the planning last minute. It a triangle between DONNA and PRL.
    - VOS is a planning/traffic management system
    - The exact localisation of VOS in the sysML model requires further verification with Alfons Schaafsma.
- TROTS (Trein Observatie & Tracking Systeem) must be added
    - TROTS generates an identification number attached to section occupation
    - TROTS follows this occupation on the rail network.
    - If a train is coupled with another train, this must be told from PRL to TROTS
    - ERTMS changes nothing in the workability of TROTS
    - TROTS gets input from ASTRIS (Occupation of track), from PRL which number is coupled (instructions)
    - Output is the location of a train with a specific train number which is send to PRL

Final remarks

The Dutch tender for implementing the ERTMS in the infrastructure has various desires which are specified for the Dutch network. It could prove that suppliers are not keen on delivering on these desires if they are not beneficial in other countries. The Netherlands could be too much ahead.

Appendix F.3 – Interview Alfons Schaafsma on ProRail VL (Summary)

Subject	ProRail VL
Respondent	Alfons Schaafsma
Function	Advisor Traffic Management of ProRail
Date of interview	29 April 2020
Date of verification	11 May 2020
Location	By phone

Important notions of the interview

- ProRail has put effort into future-proofing the requests made to the market. For instance HL3 is taken into account
- The interfaces from the safety system towards the TMS and vice versa (ASTRIS, ETIS, TROTS) make sure that the system is adaptable for changes in the TMS or the safety system.
- If the rail network is becoming more busy, the TMS might not be of sufficient quality for operation.
- Thus, a new TMS is in research. This further combines the thirteen PRL plans into one integrated plan. This is based upon the Swiss model.
- DONNA is part of the planning system and constructs timetables beforehand
- VOS is part of the management system and adapts timetables with actuality taken into account.
- PRL is also part of the TCS, by communicating with ASTRIS with ARI.
- Train Traffic Controller must be split into Signal operator and Dispatcher.

ATO addition in the sysML model

It would be nice if you add ATO in the conceptual model. That the TMS provides to the train a certain capacity band to which it is required to hold. What happens if the train driver is only monitoring because the traction and brake is controlled automatically. How this happens is described in the ERA protocols. A shift2rail working group is working on creating these specifications.

What comes to mind when thinking about adaptability of ERTMS?

A lot of energy went into constructing various formulations inserting adaptability within any contracts. Future changes towards for instance HL3 must stay possible, especially because HL3 has various benefits, like decreasing trainside equipment. ProRail has made itself strong for inserting adaptability. Other actors argue from proven technology, but if you do it that way you remain behind.

We came from a world where rail innovations meant that no further innovation would be necessary for another fifty years. This required a lot of effort and flexibility from different departments. However, this is going well.

Is the current TMS and TCS future-proof?

Yes and no. ASTRIS, ETIS and TROTS are interfaces between the TMS and the safety system. Because these interfaces translates TMS controls to the safety system and vice versa, the TMS is rather future-proof. The function of ASTRIS is to translate instructions from PRL to the interlocking and vice versa. The function of ETIS is to translate from PRL to the RBC and vice versa.

However, if more trains are going to operate on the network then these systems are no longer adequate. Other systems or updates must be implemented. We are currently doing research for another TMS.

The current situation is that you have one network plan in VOS and thirteen PRL plans for the thirteen posts throughout the Dutch network. Future plans are to make only one integrated plan for operation with the trigger for automatic route setting. This is based on the Swiss model. They also have only one plan for adjusting the rail traffic. They further have additional functionalities, like automatic conflict signalling. This system continuously checks the data outside with the planning to see if any conflicts arise. This would be useful for the Dutch network if it becomes more busy. The further to the planning systems you go, the further to leave ERTMS.

What is the difference between the planning system and the traffic management system?

The planning system operates beforehand. The traffic management system takes current actuality into account, by managing trains based on the plans and the things actually happing throughout the rail network.

What is the function of the planner from the operator?

The planner from NS works into DONNA. But the planner from ProRail is responsible to authorize the plans made by NS. Other operators do these request in another manner, with an e-mail for example. This could possibly give some discussion between planners about the optimal timetable. This is all happening in DONNA. If the requests are short-term, then it goes directly to VOS. If the request is for shunting, it goes directly to PRL.

Discussion SysML

The model has been updated with discussion in mind

Some important notions during discussion

- VOS must be added
  - Located in the TMS system.
  - PRL handles the traffic in stations. It knows the layout of the rail network.
  - VOS handles the traffic in the network. Between the stations. VOS changes arrival times. Exact routes and tracks in stations are unknown in VOS; PRL deals with routes
  - Last minute changing of the planning is a task of VOS, not of DONNA.
  - VOS has input from:
    - DONNA: makes day to day planning beforehand. If the window closes, this planning is transferred to VOS and to the PRL.
    - Planner Operator: last minute requests.
    - Planner ProRail: last minute requests
  - Output from VOS
    - Changes for times go to PRL, or new/cancelled trains
    - System state is going to the dispatcher
- PRL is half TMS and half TCS.
  - Especially ARI (Automatische Rijweg instelling) is part of PRL and operates in the TCS. This part carries out the plan through triggering the automatic route setting.
  - The parts that are about route setting, setup times et cetera, are part of the TMS system. The process plan.
- Planning system, TMS and TCS are the correct naming for the blocks.
- The Train Traffic Controller must be split up into:
  - Signal operator (treindienstleider): responsible for shunting movement. Local orders that stay within one yard. The signal operator can talk to the train driver. He works with VOS.
  - Dispatcher (verkeersleider): resolves conflicting use of infrastructure. Accepts orders from planners into VOS. You have centralized and decentralized dispatchers.

Appendix F.4 – Interview Peter Wilms on European ERTMS implementation (Summary)

Subject	Implementation of ERTMS
Respondent	Peter Wilms
Function	Independent Rail Advisor
Date of interview	11 May 2020
Date of verification	13 May 2020
Location	By phone

Important notions of the interview

- Switzerland has high focus on familiarizing with new technologies and is prepared to stop the implementation process for it. One of the reasons this can be done, is because the national government has a high focus on these innovations.
- Switzerland combines the two main strategies for implementing ERTMS. Legacy rolling stock can still be utilized, but not on newly constructed infrastructure. New rolling stock can be used throughout the network.
- Spain started early which led to various costly upgrading and updating processes.
- Denmark started implementing with a baseline that contained many faults which led to delay in the implementation.
- Two main strategies for implementing ERTMS
    - Infrastructure is constructed with dual signalling equipment. The IM is responsible for interoperability which lead to more adaptability.
    - Rolling Stock is constructed with dual signalling equipment. The operators are responsible for interoperability, which is societally most economical but leads to less adaptability.
- The railway sector has a lengthy time to market (15 years). The industry starts working on a component after regulation is known. Afterwards, the component is only released to the market if the product is demonstrated to be in compliance to these regulations.
- However, technological developments are going rather quickly (Shift2Rail program). There is a mismatch between the time to market and available technology. The Dutch ERTMS implementation could be outdated when realized.

What are interesting European ERTMS implementation processes?

Switzerland has until now the most promising strategy. It has been established as a well thought out process that watches potential new innovations. For instance, you have the replacement of GSM-R coming. Switzerland finds this innovation very promising, so they have stopped their implementation process for five years to get familiar with the new technology. More information can be found on the website on SmartRail 4.0. Furthermore, they choose to implement ERTMS for their entire country right from the start.

Spain began implementing ERTMS ten years ago. They started a bit too early because ERTMS was not mature yet. Various upgrading and updating processes as consequence. Thus the question is, how can we keep on investing while keeping invested rail corridors fully operational? How to keep early investors on-board during the innovation process?

Another example is Denmark. They started implementing but found out that the baseline originally chosen was no longer available due to the many faults it contained. In other words, the technology was not mature enough for their scheme. Thus they choose for a new scheme which required a longer lead time.

The responsible authorities in Germany put more emphasis on the ability to innovate in their concessions to railway operators. As comparison, the Dutch concession with NS is more about punctuality and travel times.

What strategies are seen in implementing ERTMS?

There are two main strategies for implementing ERTMS.

1. Infrastructure is changed such that new and old trains can operate on it. This means that the infrastructure contains two safety systems parallel with each other. In this strategy, the infrastructure manager is responsible for solving interoperability problems and paying for this. However, with this strategy you have a lot more adaptability because the IM can adapt to new technologies more easily.
2. The operators are asked to insert all required equipment for both the legacy and the new standard in their trains. This makes that trains can operate on both infrastructure standards. With this strategy, the operators are responsible for solving interoperability problems and paying for this. From a societal viewpoint, this is most economical. However, operators are generally not very enthusiastic because they are not fully compensated for this. This strategy might not be adaptable because operators only change because they have to, not because they want to. Every change could bring about disagreement and discussion.

What is the link between ERTMS implementation and the "time to market"?

The faster the feedback from the market, the more adaptable you are. In the rail sector, the average time to market is around 15 years. It is very difficult to control this process. In other words, the industry wants to see regulation first before actually starting building on a component. The industry wants to demonstrate that the product complies with the regulations before bringing the product to the market.

With other sectors, like the airline or automotive industry, a product is developed before altering regulation. If you want to be adaptive, you must construct components where you think a need exists.

ERTMS is already rather old, a concept established in the nineties. In the program Shift2Rail various innovations are researched and many goals are set. While the railway sector has a lengthy time to market, current technological developments are developing rather quickly. There is a mismatch between the market and the responsible stakeholders for implementing ERTMS. For example, the ERTMS program contains no innovations while it runs between 2020 and 2030. This could prove short-sighted because a new radio system is expected before 2025 that changes much. If the system is realized, it might be already outdated. The need to improve adaptability is high, but the structures are not there.

Why is this better achieved in Switzerland?

Rail is rather high on the policy agenda of the Swiss national government because the road network cannot provide enough capacity for the required demand. Which creates a focus on the railways. The national Ministry will adapt their agenda to changing desires of the industry. I do not know if the Dutch government has such an agenda. Besides, Switzerland chose a hybrid combination of the two strategies mentioned earlier. Existing locomotives can still operate on the network except on the newly constructed infrastructure. New locomotives can operate on the whole network. Switzerland is the first, and until now the only country that allows a train with only ERTMS equipment to operate on the entire network.

What are other examples in implementing ERTMS?

You can look at the New York Metro. This metro uses ERTMS. They choose a strategy where the industry itself came up with safety system solutions. The winning party was chosen to implement ERTMS on the metro sections. Europe has the problem that ERTMS is obligated due to its operability function between national rail networks. In other words, it is not a closed network like a New York Metro.

Appendix F.5 – Interview Bob Janssen on adaptability ERTMS and EULYNX (Summary)

Subject	Adaptability ERTMS and EULYNX
Respondent	Bob Janssen
Function	Past: ETCS and railway signalling expert of Siemens Current: Senior Data Architect at EULYNX
Date of interview	11 June 2020
Date of verification	29 June 2020
Location	By phone

Important notions of the interview

- Every small error in the data that is conveyed to a contractor is likely to cost much money to correct. Thus, the correct data is of utmost importance.
- However, in the current situation the data is conveyed between various people in paper form. This workflow is prone to unintentional errors.
- It would be better to use other methods to convey data between persons and parties. For instance the form of an ontology to convey data.
- EULYNX wants to standardize interfaces between trackside components and transfer of configuration data.
- One important method is to introduce a facade pattern, like an object controller, to allow controlling components or controlled components be changed without requiring the entire system to be replaced.
- The CSS is likely to contain a facade pattern between the IXL and the RBC, making it more adaptable towards hybrid level 3. The facade pattern is an Object-Oriented design pattern whereby systems are loosely coupled such that either system is little affected by changes "beyond the facade".

How is ERTMS currently implemented in the Netherlands and is this adaptable?

For instance you have the HSL-Zuid where they operate in a DBFM contract where it pays off to increase the availability of the track. The banks that finance the changes do not want to see additional risks. Thus, this counts also for the industry itself. They are averse of additional risks due to changes that are not specifically necessary. All in all, this is not a stimulant of adaptability.

For the HSL-Zuid, a digital twin is made to simulate to compute lost travel time that can be allocated to signalling failures. To do this, correct and loads of data is required. If you insert a change in this digital twin before you form a request to the market, and you make a mistake in the digital twin and/or in your request this will cost a relatively high amount of money. Tendering induces industry to take risks and bid at low prices. This stimulates industry to claim high compensation for variations in spec.

In the tendering process, the lowest bidder wins. If you, as bidder, realize that you bid a rather low amount you will want to earn it back later in the process. For instance, you will check the data extensively and will require relative high amounts of money to fix potential problems (mistakes in the data).

Thus, reliable and complete to-build information is of utmost importance.

Currently, when a party is chosen to build ERTMS on a corridor. A dossier with loads of pdf's are given to this party. These pdf's contain locations for signals, balises and further trackside ETCS subsystems. Much precise data is required and if you make a small mistake, you have a big problem. This could change a mistake you could have corrected earlier for 1 euro now could cost 1 million to correct. As a rule of thumb, every process step multiplies the cost by a factor 10.

Especially in the current situation, where data in the form of paper is conveyed between various people. This is especially sensitive for introducing mistakes.

What would you propose in order to increase adaptability?

To standardize this information. In the form of information through an ontology or data in the form of XML code. Both methods to visualize and communicate data. This data contains information about the number of signals, balises and length of required cable. This latter is an important factor of the cost. You want to minimize the lengths of the cables. A chosen solution is that various objects are controlled by a standardised IP connection.

Information such as required cable can be deduced from the provided information. Given an ontology, smart algorithms can take over the much of the routine work that can now only be done by specialists.

What does EULYNX do?

EULYNX standardizes interfaces.

While the air gap between train and track is already standardised, the interface between different trackside or trainside components is not. EULYNX tries to standardize trackside interfaces. Such as the interface between the interlocking and the signal or switch. The trainside interfaces are currently outside the scope for EULYNX.

All interfaces standardised are visualized in the context diagram of EULYNX. In this diagram, the blue line depicts which interfaces are envisaged to be standardised in the future.

Is standardisation a stimulating factor to adaptability?

The early systems of Siemens, the Simis C-systems, consists of an electric interlocking, which controlled field elements such as switches and signals. The question came if these systems can be kept instead of changing them to newer systems that can cope with various recent developments. In other words, standardizing this Simis C-system. However, this early interlocking controlled an object with a direct cable that runs until the heart of the interlocking. Thus making it impossible to uncouple the interlocking and field element without changing the interlocking itself. EULYNX-style standardisation through uncoupling is impossible on older intertwined architectures.

Newer systems improve adaptability by introducing an object controller. This is an interface, or facade pattern, that connects the interlocking to a certain object. The loose coupling of CSS and field element means that both can evolve at their own pace without breaking the other.

ProRail tendered their CSS (IXL & RBC) recently to the market. Is this standardised or adaptable?

It could be a political issue. ProRail has of course investigated the state of the industry. Lately, the trend is visible where the IXL and RBC are slowly integrating. The top level function of the trackside components is to the control the train. Thus, it is logical that this becomes one integrated component.

CSS is a software component and by this virtue is likely to be virtualized in future.

The current CSS is likely to be interconnected with a software facade pattern. In other words, the IXL and RBC are connected in such a way that independent functionalities can probably change without structurally changing the system. In this way both functionalities are executed, the regulation of blocks and regulation movement authorities, without being integrated. For instance, when you utilize hybrid level 3 with fixed virtual blocks, then you can alter the RBC easily with this setup.

While there is no official bidder yet, the industry is aware of the ideas behind CSS. The CSS architecture concurs with the current trend of IT in railways.

This is an enabler for Hybrid Level 3, then?

Yes. However, the migration strategy is a cumbersome issue. One strategy would be to implement axle counters with larger blocks parallel to the current track circuits. These axle counters are cheaper than track circuits. Because these techniques depend entirely on different factors, these can function redundantly. Then you would utilize Hybrid Level 3 in a safe manner without too much effort. One important factor in allowing evolution is to ensure that safety cases are written in a way to allow modifications. Currently, even minor modifications can require the safety case to be rewritten which can be exceedingly costly. Care should be taken that the safety case is system engineered *like the systems themselves*, i.e. uncoupled such that sub-systems/sub-safety cases can evolve at their own pace.

Appendix F.6 – Interview Jan Tiecken on HSL-Zuid (Summary)

Subject	Adaptability of the HSL-Zuid project
Respondent	Jan Tiecken
Function	Manager Contract Management Team of ProRail on Project HSL-Zuid
Date of interview	06 April 2020
Date of verification	22 April 2020
Location	By phone

Important notions of the interview

- The DBFM contract on the HSL-Zuid left room for discussion which decreases effectiveness and efficiency. The pace, the conditions and the extension of cooperation are not described in the contract.
- The originally agreed lead time for changes proved not realizable during the maintain phase due to non-existent consequences, a decrease of available sources after the build phase and the complexity to align the involved stakeholders.
- Leadership of the Ministry of Infrastructure and Water Management is considered fine due to availability of experts and the verification role of ProRail during the process.
- The parts project are bounded to specific suppliers due to the complexity and datedness of the chosen solution.
- The introduction of the joint KPI's were a major stimulant in the cooperation between stakeholders. This introduction also formed the environment where improvements are proposed in a joint collaboration.

What method of contracting has been chosen?

Infraspeed is a consortium between various parties including the following three larger parties, Fluor, Siemens and BAM. The HSL-Zuid is constructed within a DBFM (Design, Build, Finance & Maintain) contract based on an Anglo-Saxon thought. Thus the consortium provided financial means and is paid by the Ministry of Infrastructure and Water Management within the 25 years after construction. There have been agreements to which Infraspeed is required to hold in order to receive their payment. ProRail has been asked to manage the contract, e.g. by supervise on the performance of Infraspeed.

Why did the choice fall on a DBFM contract?

These were political choices based upon the thought that market will offer up its best price for the task. During the Build phase, the project management was done by Rijkswaterstaat.

Is this choice perceived as adaptable?

A DBFM contract must have clear responsibilities and boundaries. However, it proved to be multi interpretable and thus is quick to bring about a yes-no argument. Position is chosen dependent upon role within the project. With regard to changes on the HSL-Zuid infrastructure, according to the contract, all changes in the project are instructed by the Ministry and executed by Infraspeed. This proved a challenge for pricing. Furthermore, agreements were made about the lead times of the execution of changes, however these proved not realizable during the maintain phase. These agreements were made during the design and build phase, during which more people (State and IFS had their own standing project organization) were involved.

Why is it negative that lead times are not realizable?

Issues can appear quickly and are required to be mended on short notice in order to negate negative impact. The inability to quickly involve knowledgeable people lead to longer lead times which lead to lower operational performance. As example, more updates than originally thought were necessary within the ERTMS component of the HSL-Zuid. This was e.g. due to minor differences within the delivered trains and infrastructure that were not interoperable and due to promised backwards compatibility that was different as originally thought. The required changes, that were not that technically complex, took rather long and, as consequence, the start of implementation experienced delay.

How is the process of decision making in the updates of ERTMS?

Infraspeed and the Ministry have an agreement that a specific version should be maintained by Infraspeed during this 25 years. This version is Baseline 2.3.0 Corridor, during that time the most usable version. If for example a higher version is required by the Ministry, then the Ministry must finance this change, which would require a large budget. The technical view of experts is that Infraspeed is not able to maintain this version for 25 years and simultaneously providing the required performance, thus is required to upgrade without the Ministry financing this change.

Besides, updates on ERTMS were decided on with various stakeholders (different trains with different ERTMS versions running on the HSL Z) that were all required to align. This complex process adds to the impracticability of the original agreed lead times.

When the required operability of the system proved to be not realizable, what were the following actions?

The Ministry decided somewhere before 2008 on an update of the ERTMS infrastructure which was executed by Infraspeed. However, 2.3.0 Corridor at this time is an already dated version while technology is developing further. Knowledge about this dated version is far less than during the build phase. Thus many more hours are required for realization of changes in the system than in similar rail corridor projects (Amsterdam-Utrecht, Hanzelijn and Betuwelijn). These are examples of contracts where the build and maintaining of the system is separated.

How is leadership organized in this project?

The Ministry of Infrastructure and Water Management makes the decisions based upon interest of various stakeholders. The Ministry is also responsible for financing changes. The decision is based on a proposal made by ProRail, as initiator, in coordination with Infraspeed on manufacturability and with NS on their opinion on the proposal. The proposal is formed by the technological experts of ProRail.

How is the leadership of the Ministry experienced?

It is fine. Financial flow is between the Ministry and Infraspeed while ProRail checks the validity of the invoices.

What is the effect of the DBFM contract in the project?

The contract was setup during a time a lot of people were involved and immediately available: corresponding appropriate lead times were agreed. However, the situation changed and these lead times were not realizable anymore during the maintain phase. Furthermore, no consequences were inserted within the contract. And, as said before, there was room for discussion within the contract. And under the contract Infraspeed may regularly claim to prepare and execute the changes. All these aspects were not stimulating quick action and thus decrease adaptability and changeability of the project/infrastructure. Thus, in short, the DBFM contract does not provide a good enough environment to implement changes in the project/infrastructure.

Are there any (independent) experts involved during the process?

Most of the tasks during the exploitation phase are executed by experts within the involved companies. However, for some facets independent experts were involved. For example, a consultant was hired multiple times for implementing ERTMS changes. Sufficient knowledge throughout the preparing and building phase of the project was not the problem. The ability to actually implement or insert changes in the maintenance phase proved to be more difficult.

How is flexibility and changeability organized within the contract?

There are only two reasons specified in the contract that enables realization of changes. The first reason dealing with aspects surrounding safety. The second reason is dealing with aspects surrounding the risk profiles (of investors in the project). Infraspeed must cooperate in change requests, however the pace at which they cooperate, the extent to which they cooperate and under what conditions they cooperate is not fully described in the contract, thus is ground for much discussion. In summary, there is nearly no drive for Infraspeed to quickly follow-up on change request.

Is it possible to involve other companies in the project?

In some parts of the project it might be possible to use different subcontractors than the founding constructors like Siemens and BAM. However, on ERTMS for example you will end up with Infraspeed and Siemens anyway, as system manager and supplier. Siemens has enough sources to provide service to the specified ERTMS parts on the HSL-Zuid. However, ERTMS on the HSL-Zuid is a somewhat dated version which is very different to the version implemented nowadays, which makes it also into Siemens difficult to find timely the proven specialists. Experts from other suppliers does not understand the version and implementation of ERTMS on the HSL-Zuid, so you are bounded to Siemens to some extent. Furthermore, if other suppliers make changes to the ERTMS, they are expected to take over responsibility on safety to some extent. Due to this reason, suppliers are not keen on taking over parts of the system. This is also the case in other similar projects, like the Betuweroute. In that project is counts for Alstom instead of Siemens. In summary, if you have an entire system from supplier A, then it is difficult to get a supplier B to make changes, especially in a DBFM contract.

In what way are stakeholders kept up to date on the project?

For ERTMS it is necessary to closely cooperate between the involved specialists and parties (infrastructure suppliers, GSM-R supplier and train ERTMS suppliers). That is rather well organized.

The start of the project proved to be difficult. Many times if something went wrong or problems had to be solved, much energy went into defending own position ("it isn't our fault"). However, later in the project cooperation was more stimulated and realized. We use the supply chain approach which stimulates that data is on an open base shared between stakeholders for joint investigation of the complete chain. A major factor in this cooperation change was also the introduction of the joint key performance indicators (KPI's). Besides this major factor, stakeholders implemented improvement programs to evaluate operations all-round. These findings were then discussed extensively within the steering group which contained all involved high interest stakeholders. These groups, in alliance meetings, composed joint improvement proposals.

Appendix F.7 – Interview Ed Visser & Aad Hertogs on HSL-Zuid (Summary)

Subject	Implementation of HSL-Zuid
Respondent	Aad Hertogs
Function	Manager Operations of Infraspeed (Maintenance / Asset manager)
Respondent	Ed Visser
Function	Maintenance Engineer of Infraspeed (ERTMS expert)
Date of interview	14 May 2020
Date of verification	19 May 2020
Location	By phone

Important notions of the interview

- If a component, such as a RBC, is replaced by another supplier then various issues can occur. For example, the cooperation from the old supplier becomes less, the new supplier would require a long and costly development process and education, protocols and/or stored spare parts become unusable or obsolete due to the replacement.
- To have various suppliers in one system increases the complexity of dividing the responsibilities.
- A RBC from a specific supplier transmits in a certain manner. If this is changed, then it could disrupt the system. For instance, it could accidentally force trains to a complete standstill.
- Changing a component introduces additional risks which is not desirable for Infraspeeds point of view.
- If components that operate within SIL-4 requires a change, it takes a very long time due to the lengthy certification and testing period.

What is difficult in changing a component, such as the RBC, on the HSL-Zuid?

The signalling system is from Siemens. Thales, as sub-supplier, provided the RBC. In 2021 this RBC requires a renewal. Infraspeed expects to solve this with sufficient spare parts for the coming years or even till the end of the contract. Theoretically we could implement a RBC from Siemens due to its participation within Infraspeed. So, 2021 is an ideal opportunity to make this change happen. A change from Thales to a Siemens RBC. However, in practice, is not that easy and it gives the following issues:

- Cooperation from a supplier from the legacy system becomes less. They are not very willing to help in this change thus slowing the process.
- The supplier from the legacy system knows the system well. I would take around two months for this supplier to provide an offer for the renewal. A new supplier would need to start a development process. In the example, while Siemens knows the IXL and the corresponding track data, they do not know the ins and outs of the RBC. A new RBC would take an initial one-off payment to fund this development process. It is not an off-the-shelf product. Thales however, knows the RBC and can replace it more easily.
- Things like the education of Infraspeed maintenance personnel, made agreements and protocols must adapt to the new system.
- Replacement parts for the RBC in storage will be obsolete after implementation of a new RBC, this is only not the case by a one to one replacement
- The Safety Case must be adapted to the new system. It requires a lot of time to test the system in a test lab and by train-track integration test. The system must be certified again by a Notified Body and accepted by the ISA (Independent Safety Assessor). Siemens recently

developed their RBC, but was not customized for the HSL. This adds to the time, especially because the RBC operates within SIL-4.

- The new supplier would have to think about the actual volume delivered. For instance, a very small development project in the Netherlands like the replacement of two RBCs of the HSL compared to a very large project in Norway of 800 million gives a clear choice. Suppliers have limited resources at hand to work on projects. Resources are, for example, workhours of ERTMS experts.

Why would Infraspeed choose for a Siemens RBC over a Thales RBC? And why has this not been done in the first place?

Due to the market. Siemens is part of Infraspeed, so it would be logical to choose for Siemens. Besides, on the HSL-Zuid the entire safety system is delivered by Siemens. Except the RBC, which is sub-contracted to Thales. This was done because Siemens could not deliver a RBC during the initial construction phase between 2002 -2006, which was generally the testing phase for ERTMS

It would be better if the entire system was delivered by Siemens. This would make the dividing of responsibilities less complex for technical issues.

In practice, what are the differences between RBCs from different suppliers?

The specifications specifies what message you must transmit. However, while the RBC can be from different suppliers, also the on-board unit can be from different suppliers, such as Alstom and Bombardier. Some trains can process certain messages. However, other trains reacts differently to these messages to the extent of an complete shutdown.

What is an example of this?

This is happened in practice. There was a corrupt balise on the track. The train from Alstom (Thalys) received the data and detects it as an fault in the LEU. It continues to the next balise and receives it as normal thus continuing operation as normal. Some locomotives from Bombardier (TRAXX), when received the same data, bring the train to a complete standstill if the train driver fails to react, within five seconds, with an own counter action.

However, the on-board units from both trains are in compliance with the ERA specifications. There is still too much room for interpretation in these specifications.

What is another example of this?

The connection with the RBC can be gone for a short period. The specifications specifies how long the connection can be absent before a train goes to a complete standstill. In practice on the HSL-Zuid, sometimes these disconnections were a few seconds longer than allowed which resulted in the standstill of trains which caused delay throughout the corridor. In cooperation with the ERA we looked at the allowable period of disconnection with the question if this period can be extended without compromising the safety.

Eventually, this update of the system is carried out by various ERTMS suppliers that cooperate in a ERTMS super group (UNISIG). The change went into the ERTMS subsets. We still have a wish list of improvements for ERTMS.

One of these examples is the procedure of transitioning from legacy ATB rail to ERTMS rail on the HSL-Zuid. This is a very difficult procedure. This procedure can be solved if ERTMS is handled differently.

Does this have something to with the used baseline (2.3.0c), because this is not an official release of the ERA?

We currently use baseline 2.3.0c. However, the base is still baseline 2.2.2 with a number of change requests inserted which allows international operation between the Netherlands and Belgium. This network is backwards compatible with baseline 3 release 2. However, not all functionalities are supported.

If you look at the Hanzelijn and the Betuweroute, these are based on baseline 2.3.0d which allows different functionalities. It should be unanimous, but only in the Netherlands, we already have four different versions of ERTMS

Why is the HSL-Zuid not upgraded towards official releases of baseline 3 or baseline 2?

This is a result of the contract where we must deliver availability of the track. With this we get our funding to settle with the banks that helped us finance the entire project. The contract specifies that we operate 2.3.0c until the end of the concession (maintenance and replacements until 2031 with warranty until 2036). We do not have the incentive to upgrade to another baseline. If ProRail wants this, then a project is setup. But the initiative is not coming from us because we do not want to change the requirements of the contract.

Besides, changing a component in a safety system introduces additional risks. For example, an upgrade could interfere with operations in such a way that it results in a shutdown. We receive our payment based on availability of the track, so we do not want that. Thus, it is important to minimize risks. If operation stops then we risk a fine of millions of euros.

What where changes during the process of implementation in the past?

On the HSL-Zuid there were several maintenance releases of ERTMS. The HSL-Zuid was used as development corridor. Most of these changes in releases were before the realization of the line. To execute these changes, a team was setup. A configuration management team that was facilitated by The State. First, tests were carried out which were evaluated. Any problems were solved in this team. This cycle was completed several times.

In this cycle, the market was very involved in solving the problems. Sometimes Siemens has to change something in the IXL and sometimes it was Thales that should work with the RBC.

An example of this is the RBC we are talking about. The RBC on the HSL-Zuid is still a development version. This RBC is not fit for usage in baseline 3 because it is already outdated. There are several people currently busy with the question on how to upgrade the HSL-Zuid to baseline 3, especially with the RBC. Continue with Thales, go to Siemens or even to Alstom? However, this process is not actually started before the variation is proposed by The State.

If such a replacement happens, then the new system is implemented alongside the legacy system until it has been tested through and through. Then, and only then, the legacy system can be removed. This gives the preference to an existing supplier. Because you minimize risk by replacing parts one to one which is more ensured by using the same supplier instead of using different suppliers.

What is an example of a past replacement process?

Recently, a few new hard disks were required in the RBC. Because of the important nature of the RBC, we started the process of replacement a year early to make sure that it would go without any hiccups. These hard disks operate within a safety case, thus these must be acquired through certified suppliers. The whole process took four years! This is especially due to the length of the certifying process.

What is an example of a past state variation proposal?

The, previously mentioned, timers that determined the allowable time period of disconnection between train and RBC are a good example of this. A frequent standstill of trains on the HSL-Zuid had its impact on public opinion through media, so a SVP was put through. The various parties were brought together to come up with a solution. ProRail (as representative of The State) made the decision to change the system.

ProRail made the decision because they are representing the asset owner. Infraspeed is the asset manager and execute maintenance. At the end of the concession, we transfer these tasks to ProRail. If you want to add functionalities or assets, then it must be in the form of a SVP.

Does the concession play a role in changing the system?

We try to manage until the end of the concession with our spare parts and a service contract rather than placing a new RBC. We have a large storage with spare parts which is required for servicing the HSL-Zuid. When transferring the HSL-Zuid to ProRail in 2031, we provide enough spare parts which corresponds to a components maintenance history. These parts would be enough to provide service until 2036.

Appendix F.8 – Interview Arnold Hornung on HSL-Zuid (Summary)

Subject	Implementation of HSL-Zuid
Respondent	Arnold Hornung
Function	General Manager of Infraspeed Maintenance BV
Date of interview	13 May 2020
Date of verification	16 June 2020
Location	By phone

Important notions of the interview

- Infraspeed is responsible for safety and availability of the HSL-Zuid.
- Due to heavy wind, speed restriction or even a shutdown can be ordered on the southern part of the HSL-Zuid. The effect of this is not a responsibility of Infraspeed.
- This issue was known since the start of the HSL-Zuid (2005). The costs of a solution did not outweigh the benefits. However, due to the introduction of the ICNG, changing of the climate (stronger winds) and the availability of a sixty million euro package from The State windscreens are going to be placed with ProRail in the lead.
- Because The State (ProRail) is responsible for the final design of the wind screens, Infraspeed is not responsible for the effect of these screens. Any costs that are made by Infraspeed to place the windscreens are compensated
- Infraspeed wants to minimize risks. If a change introduces additional risks Infraspeed will want to receive exemption for the risk or a risk contingency needs to be added to cover this risk
- The safety and availability of the assets in the infrastructure are on a high level.

What is the situation on the HSL-Zuid bridge that crosses the “Hollands Diep”.

Various situations on the HSL-Zuid can be traced back to the issues with the Fyra. The overall performance on the HSL-Zuid was below the standard. Infraspeed has KPIs that focus on the safety and availability of the track (99.0% availability) which are on a high level. Therefore, a lot of the performance issues are related to the rolling stock that is used on the HSL-Zuid.

To improve the overall performance on the HSL-Zuid, a sixty million euro package was made available by The State. This package is meant for measures that should be realized before the end of December 2020. Of these measures is about the bridge. Another important aspect to the bridge is the introduction of new type of rolling stock, the ICNG. The rail sector is rather sensitive on public opinion with the introduction of this ICNG. In short, the introduction must be smooth!

This brings us to the bridge that crosses the “Hollands Diep”. This bridge is sensitive for wind, which is logical because it goes over the Moerdijk. From its original design it is known that, if a high-speed train crosses the bridge with 300 kilometres per hour with heavy wind, it could happen that the train is blown of the bridge. Therefore, anemometers are placed to determine current wind speeds. If the wind is too heavy, a TSB (Tijdelijke Snelheids beperking) / TSR (Temporary Speed Restriction) is inserted. This speed restriction is for the entire south section. So between Rotterdam and the Belgian border. The allowable speed is determined on the current wind speed. There are even examples that entire train operation was shut down.

This is undesirable of course. This dossier exists since the start of the HSL-Zuid (2005) and is discussed between stakeholders in periods with heavy wind. The traveller experiences an immediate effect. If a few months went by without heavy wind, the amount of discussions became less.

Who is the responsible party?

Infraspeed, from the start, has nothing to do with this issue. We are responsible for the availability of the infrastructure. If with heavy wind the trains operate or not, this is not part of our responsibility because the infrastructure is still available. However, if an asset fails, such as a switch, then this is our problem. We cannot do something about the strong wind, thus this risk is divided between stakeholders NS, Infraspeed and The State.

Complaints of travellers that experience delay due to this wind go to NS. NS, in turn, will talk about this issue with the Ministry with the proposal to solve this issue Then in turn, the Ministry, will devise a state variation proposal to Infraspeed. The Ministry has a contract with Infraspeed. However, contract management is outsourced to ProRail CMT.

Which measures are taken to minimize the effect of the wind?

First the speed restrictions. Secondly, from the sixty million package, windshields are placed on the west-side of the track. This is currently an ongoing process.

In what way are changes put through in the contract?

If The State requires a change (State Variation Proposal), Infraspeed composes a price and provides information about the corresponding effect.

How are events that have an impact on performance assigned to specific stakeholders?

If a train stops on the track, it is a task primary for Infraspeed to determine the reason behind this stop. If a switch fails it is our problem. If a train fails or the train driver brakes than we are protected for consequences. In the contract we distinguish 3 situations:

1. an ADE (Availability Deduction Event): the non-availability is for account of Infraspeed.
2. a NAE (Non Attributable Event): these are specified events. The non-availability is not for account of Infraspeed, and if costs occurred these will be reimbursed.
3. a No ADE (No Availability Deduction Event): if it’s not an ADE nor a NAE, it’s a No ADE. The non-availability is not for account of Infraspeed, but if costs occurred these will not be reimbursed.

What happened in the case of the “Hollands Diep” bridge?

Budget became available as mentioned earlier and with the introduction of the ICNG, stakeholders want to avoid problems, for instance due to wind on the HSL-Zuid. If the ICNG is introduced and experiences delay due to wind on the HSL-Zuid, then this could have an impact. This gave pressure on the planning, the windscreens need to be placed before the ICNG is introduced.

Why took it until now before this problem is dealt with?

The effect of the problem is not that large. The frequency to stop operations due to the wind is very low. The Thalys and the Eurostar E300 that operate on 300 kilometres per hour experience the most delays. The rolling stock that operate with 160 kilometres per hour experience much less delay. If you insert a temporary speed restriction of 160 km/h then it does not have any effect on the latter. This can lead to rerouting of the High-speed trains on the conventional network while the conventional locomotives can still use the HSL-Zuid. The ICNG must be able to operate with a speed of 200 kilometres per hour on the HSL-Zuid.

The benefits did not outweigh the costs and the consequences were accepted. While the option to place windscreens was always known, also during the construction of the HSL-Zuid, it was never put through for design and possibly financial reasons. While the actual effect of the wind was possibly not very clear, the issue in itself was known throughout the process. But the reason just mentioned accompanied with a changing climate with stronger winds, led to the decision to place windscreens. The entire steering group integrally supported this decision to place the windscreens.

What happened after the decision to construct windscreens?

A French specialist was hired by ProRail which took the lead in this project together with The State. Also Witteveen+Bos is currently involved in composing the definitive design. After this, Infraspeed takes over in placing the actual screens. So, Infraspeed will make the construction design, do the installation of the screens and maintains these until the end of the concession (end of 2031). The maintenance consists of, for example, inspection and cleaning. Infraspeed will get a compensation for their work. If workers from other companies are required to work on parts of the HSL-Zuid, these workers are always accompanied with a safety guide from Infraspeed.

This example is unique in the list of SVPs (State variation proposals). Many of the SVPs are from the start to realization task of Infraspeed. In this example is The State responsible for providing the definitive design.

Why did ProRail this, and not Infraspeed?

The question was not specifically asked to Infraspeed. Besides, Infraspeed did not interfere in the process to the specialist nature of the project.

How does certification process work with the bridge?

There are various organizations that perform inspection and give out certifications on safety. Several questions were asked about the safety of the bridge, especially if this bridge will have an increased weight load with the wind screens. This certification process requires a lot of work.

What are Infraspeeds obligations in case of a SVP?

If The State requires a variation, then Infraspeed has to comply. However, there are three reasons specified in the contract when Infraspeed can decline:

1. If the safety is compromised
2. If no funding is available
3. If the required permits are not given for the change

Discussion mostly arise on the defined scope, costs and delivery time.

Is the chosen form of contract satisfactorily?

It is very clear where responsibilities lie. Responsibility for safety and availability lies with Infraspeed. If you let a third party place the windscreens on the HSL-Zuid, who is responsible then? To clarify this, there is agreed that every change on the HSL-Zuid will be done by Infraspeed. This contract is setup by The State. Infraspeed operates decent within this contract. For example:

A discussion was held for two years about the implementation of a change in the ERTMS version. This costs of this change were not very much when comparing it to the total project throughput. The State would like to change a certain parameter in ERTMS, however Infraspeed was very happy with the current (working) software. Every change in that system could potentially introduce problems. Due to the contract setup, Infraspeed does not want to introduce additional risks. If Infraspeed does not receive exemption for the risk of changing the system, then a risk contingency needs to be added to cover this risk which would increase the price. So, if a component of this change would cause problems, we might get heavily penalized. It is a risk we cannot take.

Infraspeed also has to consider risks minimization, which is logical if seeing the contract. If we are going to implement a change, we must convince the experienced technical advisors of the banks.

If you look at our KPIs, safety and availability of the assets of the infrastructure, it is formidable. This is consequence of the contract. However, when focusing on adaptability. We have agreements that all choices are well substantiated and well researched, this needs to be done thoroughly.

Appendix F.9 – Interview Gérard Hoeberigs on HSL-Zuid (Summary)

Subject	Implementation of HSL-Zuid
Respondent	Gérard Hoeberigs
Function	Policy Advisor Ministry of Infrastructure and Water Management
Date of interview	22 May 2020
Date of verification	25 May 2020
Location	By phone

Important notions of the interview

- A timeline of events surrounding a change on the RBC :
    - 2009 - From start of operation there were connectivity problems between the train and RBC which caused trains to stand still on the HSL-Zuid.
    - May 2011 – A task force was setup to solve any problems.
    - Dec 2011 – The task force delivered an advice and solution.
    - Apr 2012 – A decision was made which steps should be taken.
    - Apr 2012 – A discussion started about responsibility and finance.
    - Dec 2013 – It came to an agreement on the corresponding conditions.
    - +/- Sep 2014 – The change was put through
- The problem consisted of two parts:
    - The first problem was that the lead time of the impact analysis was not specified which allowed a lengthy process. This was also due to the limited available resources at Siemens and Thales.
    - The second problem was that rather steep conditions were proposed by Infraspeed for the Ministry with the value change. Especially the exemption of corresponding risks surrounding the signalling system until the end of the concession.
- In the end, these conditions were let go. However, the invoices from Infraspeed that on the changes were considered rather high by ProRail CMT.

After realization of the HSL-Zuid, there were some problems with connectivity surrounding the RBC?

From the start of operation (2009), there were connectivity problems between the train and the RBC. These problems caused disruption of operation (standstill of trains).

In May 2011, the steering group of the HSL-Zuid (chaired by the Ministry), setup a task force to solve these communication problems. This task force consisted of various experts of ETCS from various stakeholders (From six organizations: Infraspeed, NS (Hispeed), SNCF, ProRail, Bombardier and MobiRail).

In December 2011, this task force provided an advice and solution to the steering group. The advice argues that some identified values must be changed in the RBC.

Two values are chosen to be changed in April 2012. One National Value that corresponds to the necessity to stop a train after disconnection to the RBC. One parameter that changed the frequency of the transmitted general message of the RBC.

Between April 2012 and December 2013 a discussion was held between stakeholders on conditions that were focused on finance and responsibility. At first, the discussion was held in the usual manner, between ProRail CMT (contract management team) and Infraspeed. When it could not be resolved on this level, policy advisors of the Ministry were involved. Thirdly on the level of directors which led to nothing. Finally, when the Secretary of State and the German Director of Siemens and Thales met on 8 October 2013, they came through with a commitment and the needed information to complete the change request process. After this agreement, the change was processed and the realization phase started, which can take around 9 months (September 2014). I cannot confirm if the change was actually done around September 2014, because I was not working on this dossier during this time.

Why did the problem required the Secretary of State and the German directors to get involved?

The Secretary of State is the last person you want to get involved. We had conversations up to the Director General of the Ministry and President Director of Siemens Netherlands. All these conversations did not lead to action in solving the problem.

When all this happened, the Secretary of State called the German directors on their responsibility to come with a proposal for the change without any unacceptable conditions. After which, a proposal was given which led to agreement.

The problem consisted of two parts. The first was about the impact analysis. This analysis provides an extended overview of the effects of the change. This is responsibility of Infraspeed to conduct. However, Infraspeed cannot perform such an impact analysis themselves. You will need the specialists of Siemens and Thales. However, these specialists had limited amount of time. The resources for such an analysis were limited, which led to lengthy delays. The discussion on the highest level led to the availability of the specialists to make such an impact analysis with a corresponding planning. This was important, because if such a planning has not been provided yet, The State cannot make a decision on the proposal.

The reason that this could happen is that, while the process surrounding a SVP is described extensively in the contract, the maximum lead time for preparation of an impact analysis is not specified in the contract. For other parts a maximum lead time was defined.

The second problem started after the completion of the impact analysis until December 2013. To change the parameters, Infraspeed proposed several conditions. One of these conditions was that if something went wrong with the signalling, Infraspeed could point towards the parameter change without actually proving this argument. The condition was to hold until the end of the concession (2031). This was obviously not preferred by the Ministry, because if something goes wrong on the HSL-Zuid, Infraspeed could just point to this change and thereby avoiding any applicable fines. In the last discussion between the Secretary of State and the German directors an agreement was closed without any of these additional conditions.

Why did Infraspeed reach an agreement about this change without these additional conditions?

This is a question which can only be answered in opinions instead of facts. I do not know exactly. However, when a Secretary of State invites the German directors of Siemens and Thales for a conversation, more subjects play a part than solely this parameter change. Therefore, Siemens might want to maintain a good relationship with The State. Besides, I think that the given demands by the suppliers were rather steep for the Ministry. They were aware of that themselves and that is why they could eventually let go of these conditions.

Opposite of the conditions that were let go, Infraspeed given invoices for this change which were considered rather high by ProRail CMT.

What was the value change and what was its corresponding effect?

When the change was put through, this had a major effect:

- National Value change (M_NVCONTACT)
  - From the situation where, if the data flow between track and train is lost, the train is set into train trip mode which requires that the train stops to a standstill with should be followed by a hard reset of the on-board equipment.
  - To the situation where, if the data flow between track and train is lost, the train only starts braking. However, when connectivity is regain during braking, the train can continue operating as usually.
  - The effect was a reduction of 70% train standstill due to a loss of connectivity. In other words, quite some of reduction in corresponding delays due to loss of connectivity.
- Parameter change (parameter is called Grote T / Heartbeat)
  - The frequency where the RBC transmits a general message to check connectivity. If the train receives a message so it knows that it has connectivity. Before the parameter was changed, the frequency was a transmission of every 14 seconds. Afterwards, this was changed to every 8 seconds.

How changeable is this parameter (Grote T / Heartbeat)

The setting of Grote T / Heartbeat is different per RBC in the Netherlands. For instance, we have two RBCs from Thales on the HSL-Zuid. We have Alstom RBCs on the Hanzelijn and Betuweroute. Thirdly we have Bombardier on Amsterdam-Utrecht. With the latter, the RBC from Bombardier, it has no timer that specifies the frequency of the transmission. It transmits a general message for every received position rapport. No position rapport, no transmission of a general message. In the RBCs from Alstom and Thales, this parameter, the frequency of the timers, is adjustable.

This parameter is not specified in the specification of the ERA. It should be adjustable as seen in the example in the HSL-Zuid. It is still not specified in the B3R2 specifications.

How changeable is a National Value?

National Values can be specified by a national Infrastructure Manager and are transmitted by balises to the trains. However, trains that utilize a certain National Value because they operate in a certain country are tested and certified for this specific National Value only. So, trains still cannot cross the border to a country with a different specified National Value, because it is not tested and certified for this different usage. This is clearly not stimulating interoperability.

It should go a situation where an entire range of National Values should be tested and certified to ensure operability between different countries. This could be done in simulation or test laboratories.

Appendix F.10 – Second interview Jan Tiecken on HSL-Zuid (Summary)

Subject	Second interview on adaptability of the HSL-Zuid project
Respondent	Jan Tiecken
Function	Manager Contract Management Team of ProRail on Project HSL-Zuid
Date of interview	10 June 2020
Date of verification	15 June 2020
Location	By phone

Important notions of the interview

- The project on the windscreens is unique because ProRail delivers a definitive design. In other SVP's all tasks are executed by Infraspeed.
- The split between definitive design and realization design is a discussion point between parties. In short, what is part of which design. This is ultimately a discussion about responsibilities.
- At the start of train operation on the HSL South, the consequences of limiting the speed due to strong wind were accepted and expected less frequent than realized. Later, because of the probable high price of the windscreens, it took a few years to establish an acceptable business case for the placement of the windscreens.
- The contract provides three reasons for Infraspeed to stop a SVP. Summarized and freely translated:
    - If the intended change does not lead to obtaining the permission and / or license (from third parties) required for the implementation
    - If the change adversely affects the safety of the HSL Assets
    - If the change causes the infrastructure provider to lose its funding for the HSL Assets
- While the solution to the connectivity problems were clear, two discussions delayed the execution of this solution. One was about the cost of the change. Another was about the potential additional risks that the change would introduce.
- The shareholders of Infraspeed are averse of additional risks.

What are the conditions of the placement of the windscreens on the "Hollands Diep" bridge.

It is no standard project. Normally, all parts of the SVP process are carried out by Infraspeed. However, with this project we had worries about the competitiveness of Infraspeed and the complexities in a specific area. That is why ProRail in consultation with the Ministry tendered the engineering of the DO to a third party.

We considered that the placement would also be done by a third party, thus designating it as an "excluded asset". In other words, an asset that would not be part of the RIA (Restated Implementation Agreement). This would be unique and this process would contain certain risks.

Ultimately, the Ministry chose a method where the actual realization of the windscreens would be done by Infraspeed. So, ProRail would deliver a definitive design of the windscreens and, in turn, Infraspeed will translate this design into a realization design. We are currently in this phase.

With this realization design, a cost estimate will be composed by Infraspeed including corresponding conditions. There are some discussions about the finished definitive design, whereas Infraspeed argues that it is not finished yet because it has to be changed because of elements in their realization design. This is mostly because ProRail argues that some parameters of the windscreen must be further defined in the realization design. However, Infraspeed argues that it is part of the definitive design and that these parameters must be added to the DO

This has to do with assigned responsibilities. Everything that could point towards this definitive design (DO) could point towards the Ministry. Certain things on the construction and the effect of the screens are responsibility of the Ministry.

Who is responsible for the disrupted operation due to strong wind and why?

This is not a risk that is contractually assigned to Infraspeed. I am not sure, but according to me it is a risk that was seen later in the process of the agreement on the RIA. Due to the combination of the environment (high placement of the rail and a few windbreakers) and the operational high-speed trains (more sensitive to strong wind) it is a risk that has to be mitigated. That is the responsibility of the Ministry.

To counter this risk, a wind alert system is installed which enables to alter the maximum speed due to strong wind. This system was built by Rijkswaterstaat and is taken over by ProRail.

Why did it take that long to place the windscreens?

It took some time to analyse what the contribution of the wind was on the Performance of the HSL South transport system. At the start of the HSL-Zuid, the issues related to strong wind did not stand out compared to other issues which led to more delay or disruption.

From approximately 2010, the option to construct windscreens was considered. However, it was known that this change would be very expensive. A few years were required to establish an acceptable business case for the placements of these screens. From approximately 2010 onwards we classified all malfunctions on the HSL-Zuid which enables a more substantiated argument for the placement of those windscreens.

Which reasons could be given by Infraspeed to stop a SVP?

The reason mostly pointed towards by Infraspeed is a negative effect on safety. There are three reasons given in the contract. Summarized and freely translated:

- If the intended change does not lead to obtaining the permission and / or license (from third parties) required for the implementation
- If the change adversely affects the safety of the HSL Assets
- If the change causes the infrastructure provider to lose its funding for the HSL Assets

Why did Infraspeed agree with the parameter change on the RBC that corresponds with the connectivity problems (M_NVContact and Grote T)?

The chosen parameters were accepted as a solution to the connectivity issues in the ERTMS chain. All stakeholders agreed that, if these parameters were changed, it would improve the performance.

However, there were two main discussions with Infraspeed. One was about how much this change would cost. Another was that additional risks could be introduced by changing parameters deep in their software. Infraspeed argued that they operated already within the contract and that changing the system could affect their performance. This argument had mainly to do with unintentional and unexpected effect to other parameters due to the change of M_NVContact and grote T. This was discussed extensively.

ProRail CMT argued that this was a business risk that belonged to Infraspeed as system manager. They have the technical know-how.

Ultimately, in order to put through this parameter change, an existing arrangement in the form of an already existing supplemental agreement was altered. This agreement specifies that if a change in the system led to malfunctions, this must be quickly fixed by Infraspeed (by temporarily returning to old software or actually fixing the problem) and if it proved to be a consequence of the change, then Infraspeed is protected against the performance consequences. The costs that belong to the repair itself is responsibility of Infraspeed.

However, Infraspeed must prove that the issues are a consequence of the change. This obligation to provide evidence is a discussion point. ProRail and the Ministry want to maintain this obligation, just because it is difficult for another party to understand and analyse an issue in an unknown system.

The shareholders of Infraspeed are averse of additional risks. Every SVP could prove to be another discussion on allocation of risks again.

Appendix F.11 – Interview Jelle van Luipen on RouteLint (Summary)

Subject	RouteLint implementation
Respondent	Jelle van Luipen
Function	Program manager Innovation of ProRail
Date of interview	23 April 2020
Date of verification	24 April 2020
Location	By phone

Important notions of the interview

- RouteLint is a product of the desires of the user (traffic controllers and train drivers)
- RouteLint uses already available data from ProRail systems
- To generate support of the users, well organized sessions were held and a simulator was built. This even brought various people to pledge to help RouteLint become a success!
- To generate support of the decision makers, the right people need to connect to each other. Visualizations through simulations did help
- It was important for the success of RouteLint that it could operate within SIL-0. This choice was made because there was no alternative.
- However, still various extensive safety studies were executed before adopting the innovation.
- It was important for the success of RouteLint that the provided data could be handled in a flexible manner, thus operators could adopt it in a manner that aligned with their current IT policy and operational processes. Besides, responsibility of risks were minimized for ProRail in this manner.
- A lot of effort was required at the start of adopting RouteLint to update the software. Later, due to new IT developments and eagerness of operators, the software was updated via app-stores.

Where did the idea of RouteLint come from?

I started in 2002 in the rail sector with the notion that, if you want to regulate the world, you should maintain enough flexibility to handle what the world gives you. Thus, RouteLint started out, not as Design task itself, but as consequence to exploration with the actual users (train drivers and traffic controllers). This research did clarify the need for the ability to exchange information. Furthermore, it should be based upon information and data flows that already exists, such as the PRL system. During the start, no further goals, such as punctuality or economical goals, were defined. It was a social innovation, the train drivers and traffic controllers were brought closer together. It was an organizational innovation, because during that time ProRail and NS were split in such a way intercommunication was minimal. It was an ICT innovation, for the first time such a system was brought in. It was a technological innovation, in the way that information was gathered and distributed.

How were stakeholders aligned?

First, I asked around what the desires and requirements were in the field. There was a lot of resistance in the rail sector towards this idea. The rail sector is a rather empirical sector who first want to see actual operation before believing this will work and then implementing it themselves. There is little imagination in the sector. There were two groups of people that must be convinced. First the users and second decision makers.

To generate support in the users various sessions with users were held. During these sessions users visited each other's workplaces. These sessions were organized in 2003 by Philip Capper from New Zealand, who led users through the process[1] while even generating enthusiasm for the product. These sessions were very well guided using visualizations beside words which allows every attendee to give their opinion. Besides these session, users were put to work within a created simulator while giving them more data step by step and asking them for feedback. Various users were enthusiastic in such a way that they pledged to help RouteLint to become a success!

To generate support of the decision makers the right people talked to them instead of sending them ideas on paper. The simulator was a good tool to make RouteLint concrete for them. It proved to be important to provide conversation between actual train drivers and traffic controllers and decision makers. During a week of testing in 2005, I continuously arranged that the right people met the right people in the cabin of real trains. These were decision makers from companies like DB Cargo, NS and ProRail.

After 2005, it was as good as sold.

Where there safety issues in implementation?

This was studied rather extensively. The point of focus was the diversion of the train driver, which is rather difficult to measure objectively. While it operates within SIL-0, there must be made a safety case to show that RouteLint was not endangering operations. As said, this was done rather extensively so this did not cause any problems during implementation.

How was the technical implementation?

Data is harvested in data systems of ProRail. This data is sent as text string (about 100 characters) towards an app, which is managed by an operator. RouteLint contains a set of rules that can translate this text string towards visualizations. At first, ProRail designed a standard client with own visualization. However, NS designed an own client with visualizations with the data send by ProRail. This system is called TimTim and shows, for instance, also an indication of the block length as an extension to the ProRail client. While this standard client is still available, ProRail allows customers of RouteLint to design their own client with visualizations. ProRail just delivers the data. It is important to allow flexibility for customers to insert this tool in their own way in their own businesses.

In 2009 there were no apps and it was difficult to update the software. The effect of this was higher than originally thought. It required a lot of effort. 1100 train drivers must go to a certain spot to wait for 5 minutes while the software was updating. This changed towards the current state in which the software is acquired and updated through an App-store. This development was in the last five years. This change was carried out by operators themselves based on IT policy. Operators themselves determines their own business case with the data.

[1] Cultural-Historical Activity Theory: *http://www.bobwilliams.co.nz/ewExternalFiles/activity.pdf*

Who is responsible for the risks of the system?

An additional benefit of the implementation method as said earlier, is that the responsibility of risks of ProRail is minimal. What the train driver does sees and does within the cabin is responsibility of the operator. Responsibility of risks are accepted due to the benefits it delivers, also because it operates within SIL-0. However, there have been several extensive safety investigations executed by operators before actually adopting the system.

Have there been any updates to the system recently?

Yes, it shows real-time information about the speed of the train. Besides that, the interface and required data have been nearly identical for 14 years. We tried to design and maintain it as simple as possible. For this, also have hired several ergonomic designers. Besides, it is based upon available ProRail sources which have a lengthy technical turnover time.

Appendix F.12 – Interview Johanna Knijff on RouteLint (Summary)

Subject	RouteLint implementation
Respondent	Johanna Knijff
Function	Past: implementation manager of RouteLint of ProRail Currently: Program manager Automatic Train Operation of ProRail
Date of interview	24 April 2020
Date of verification	28 April 2020
Location	By phone

Important notions of the interview

- To generate support of stakeholders and to form a lasting relationship, ambassadors were appointed during the first and the second phase of RouteLint.
- At early stage, before a large scale test, ProRail and NS signed an agreement where they pledged to adopt RouteLint if the test succeeded in various points. Various agreements were signed early on which helped during the second phase of RouteLint.
- The financial crisis led to RouteLint being on hold. Luckily ProRail maintained the software.
- A train accident (Singelgracht) in 2012 led to questions about rail safety. Thus giving alignment in the rail sector, which accelerates the implementation process for RouteLint.
- Development of the software was well organized through use of SBOPs. Software maintain partners that have an ongoing contract with ProRail.

How started the implementation of RouteLint?

RouteLint had a good base for implementation. The desires of the end users were well researched. However, a large task was still left, the actual implementation. For instance, the allocation of required finances in itself was a very large task. The required substantial explanation and lead time are rather large. However, when the required budget was free we started with development. What rather well was organized was the use of SBOPs (Software Beheer en Ontwikkel Partners). We have contracts with software maintain partners that can help develop a product. This process is much easier than giving a tender to the market every time you require a change.

How was cooperation with the involved operators?

We went to train operators. The difficulty is that there is never only one person. We made agreements with one, however others also want their say in the matter. There are many directors and actual users that must be taken into account during the process. Especially to take users into account during the process is difficult and requires a lot of time. To do this, we have, among other actions, appointed ambassadors within the end users group. These ambassadors represent, for instance, the train drivers. This was experienced as very helpful. Furthermore, it is very important that you work with aligned counterparts at stakeholders. With RouteLint, this meant the replacement of a program manager at an important stakeholder. The implementation of RouteLint must be carried by all, not only the infrastructure manager. The relation is very important.

In what way is the relation kept well in the RouteLint implementation?

In the first phase of RouteLint, there was an improvement program which led to a large scale test on one corridor. Before this large scale test, ProRail signed an agreement with NS pledging that if the test succeeds on various important factors, then we go over to implementation. This test was with hundreds of train drivers around The Hague. This test went very successful.

How ended the first phase of RouteLint?

Around 2009 we encountered the financial crisis. NS evaluated their portfolio and concluded that RouteLint was too labour intensive. Thus setting RouteLint on hold. This had impact on the involved ambassadors, involved train drivers and ProRail. Especially the users had a need for the release of the product. That this group was involved extensively earlier during the first phase repaid during this event. However, also directors at ProRail started evaluating RouteLint after the choice of NS. The benefits are lost if an operator like NS makes such a choice. Thus, the whole project was uncertain. It required a lot of effort to maintain the innovation because if you set such an IT innovation on hold for three years, you can start over. So the SBOPs kept it running with low budget on the ProRail architecture.

How started the second phase of RouteLint?

Unfortunately, a train accident happened in 2012 in Amsterdam. This raised various questions about the safety and the potential preventability through technologies. Managements of various stakeholders were brought together to improve safety. This was further stimulated by the Ministry by prioritizing a focus on safety by forming the STS-improvement program (Stoptonend sein passages). One of the potential safety improvers was RouteLint. From this point, development of RouteLint had a high priority. The crisis led to the acceleration of implementation. Furthermore, the introduction of the STS-improvement program let also to available budget. The Ministry and various managements of stakeholders were behind the adoption of RouteLint.

How went the second phase of RouteLint?

There is much noise in the communication in the rail sector. Stakeholders had their opinion on RouteLint based upon just thoughts and not facts. It was important to have some continuity in staff during the first and second phase of RouteLint, people that actually know what happened during the first phase. This continuity also led to the availability of the ambassadors that were established during the first phase. The relationship was very good, so these people were still eager to help.

So when the second phase started after RouteLint was set for three years on hold, we did not have to start from zero. We had a product, we had ambassadors, we now had support and budget.

The first thing we started was the safety case for RouteLint in cooperation with the operators.

Were there any questions about the safety of RouteLint?

A bureau was hired for the CSM (Common Safety Method). Throughout the process, a lot of discussion was about the safety. But because we kept to the fact RouteLint was an advisory system. Besides, various management teams had a lot of trust in the project, which was generated by the ambassadors.

How was leadership organized in the project?

The Ministry imposed that the rail sector should be safer. ProRail and operates feel responsible for safety. There are documents signed by parties that this is indeed the case. Thus, it is important that agreements are made. It proved very helpful that managements of stakeholders and the ministry was behind RouteLint during the second phase.

Did RouteLint had support during the second phase?

Through the ambassadors, a lot of lobby projects and a that people experienced earlier It was a simple product and easy to oversee. The first test was on a single corridor which showed early in the process that the product was safe.

The documents describing RouteLint to decision makers are formed in cooperation with train operators. Both “languages” are present in the document.

Who made the decision to continue with RouteLint?

A wide team of directors within the rail sector made this decision, after that the Ministry imposed this. Various measures were composed by a team of directors after an exploration research what innovations could improve the safety. RouteLint was quick to arise. This team of directors was very quick to make decisions. The focus was there and thus quick decision making was the consequence. It was very helpful that goals and interests were aligned and that the steering group consisted of only executives. During the first phase, interests were less aligned.

The money for improvement was given by the Ministry and the goal was set. With RouteLint the ministry was not inside the steering group, but this was not the problem. The goal was clearly defined as the Ministry authorized the STS-improvement program and thus keeping attached to the process.

Appendix F.13 – Interview Ramon Lentink on RouteLint (Summary)

Subject	Adaptability of the implementation of RouteLint
Respondent	Ramon Lentink
Function	Past: Program Manager RouteLint of NS Current: Manager Engineering and Experimenting of NS
Date of interview	06 May 2020
Date of verification	12 May 2020
Location	By phone

Important notions of the interview

- RouteLint consisted of two phases. In the first phase the goal was to improve on efficiency. In the second phase, the goal was to improve on safety. During which it was implemented.
- There were three subjects that required a lot of effort during the second phase. The first was to provide a well performed risk analysis. The second was the reliability of the RouteLint data source. The third was the education of train drivers.
- During the second phase and with actual implementation, one of the goals was to adopt to a minimal amount of changes to make the process manageable.
- The platform that replaced the Railpocket, TIMTIM, can provide more functionalities due to the different method it utilized data and by filling in potential blanks with new data.

How was the process of implementing RouteLint?

It consisted of two phases. In the first phase, the main goal was improving train efficiency. I was involved during the second phase. The first phase stopped because there were easier methods to increase efficiency than using RouteLint. The second phase started again after a research done in the STS-improvement program (Stoptonend sein). During this research, RouteLint came as a potential solution for improving rail safety.

Which subjects required effort in the implementation?

I will share some subjects (pillars) that required a lot of effort:

1. To provide a well performed risk analysis, such that we can implement this innovation in a safe manner. This was difficult because train drivers must look to the application RouteLint on the device Railpocket instead of looking out the window. Especially within the 40 km/h area. Diversion is very dangerous within this area. If the train is going through such an area, the application RouteLint automatically shut down. This was no change, but it been there throughout the implementation process.
2. To make the data source, RouteLint, more reliable and more usable. Many similar systems require a reset once in a while. For RouteLint, various of these reasons have been eliminated such that the application works more reliable. Besides, we tested the functionalities of RouteLint with various train drivers. The feedback was translated to ProRail and this was used for adapting the data source.
3. Education and training of train drivers. Is this something you want to obligate? NS choose for a voluntary use of RouteLint for all train drivers. In other words, drivers can check if the system helps you. Which sources must be required to provide in the need for education. RouteLint became part of education of new train drivers and various meetings were being held to inform

the group of current train drivers. This was also done with the ambassador train drivers and walk-in sessions.

These were all subjects that were expected in the implementation.

Were there any changes during the implementation?

The risk analysis required more effort than originally thought. We hoped to use more of the information gathered during the first phase. ProRail is responsible for the quality of the data. NS is responsible for what happens in the cab. For this, an external party was hired to help with the safety case.

RouteLint was inserted as application in the Railpocket. A device that precedes the current smart phone. After implementation of RouteLint, this is changed towards the TIMTIM, a tablet for train drivers. The Railpocket was at its end of its lifespan. This consisted of a change in visualizations and functionalities due to the extra available room on the screen. Examples of the changed functionalities are that the TIMTIM provides information about the track circumstances and the lengths of the actual track sections which are visualized by setting the length of a certain block in correspondence with the actual length of the section. The extra functionalities were acquired by extending the amount of data RouteLint provided and by combining already provided functionalities.

So, not many changes during the implementation?

This was one of the goals. To quickly make RouteLint operational with the train drivers. We tried to minimize the amount of changes to the system to make it manageable.

How was this done? To minimize the amount of changes?

It was difficult. For instance, you can see the end of the Railpocket. So, you must take that into account. Besides, RouteLint has been implemented throughout the sector. Thus, all operators have access to a subscription on RouteLint and have their own vision with the system.

Furthermore, it is based on the work done during the first phase of RouteLint. This made it easier to implemented it with minimal amount of changes.

Appendix F.14 – Interview Madeleine Schellaars on RouteLint (Summary)

Subject	Implementation of RouteLint
Respondent	Madeleine Schellaars
Function	Past: Project Manager (1st phase) RouteLint of NS Current: Business Consultant Data & Analytics of NS
Date of interview	13 May 2020
Date of verification	24 May 2020
Location	By phone

Important notions of the interview

- Because RouteLint was an application on the Railpocket which required a power supply, a holder was design which brought about a process of acceptance. At the same time, train drivers were educated to use the system. It looked like an actual implementation of software instead of an experimental project. This led to that train drivers became attached to the system.
- Other reasons that the train driver became attached was the good functionality of the system, that the interface was designed with the drivers themselves and that PR was done nicely using ambassadors and a small movie clip.
- The business case was not successful which led to the stop of the project. This was disappointing for all involved stakeholders. Another reason that the project was not continued was that another simple method was in development during the same period that increased energy efficiency as well. While it was not intentional to compare the two innovations, the latter was chosen over RouteLint by NS. It was just bad luck for RouteLint.
- RouteLint required no changes in the interface throughout the first phase. This was the case because it was constructed with the actual users themselves.
- If a change would be necessary, all stakeholders would cooperate to make this happen. Furthermore, the systems are rather uncoupled. So a change towards a tablet, for instance, could be done independently of the ProRail source systems.

When were you involved in the project?

In 2007 the formal decision was made to start an experiment which was intentionally called "Proefbedrijf" (operation experiment). In 2010 the decision was made to stop this experiment. Throughout this time, I was the project manager.

What was this experiment about ("Proefbedrijf")?

A device was built into the cab. The software was shown on the Railpocket. But because the Railpocket required electrical power supply, a holder was designed. Which meant that a formal process started for changing the construction of the cab which must be accepted by our consultants. The train drivers were educated for RouteLint at the same time.

All these processes looked like we were actually implementing a piece of software. However, we were only proving the business case with an experimental project within a small area of the rail network. This project was used as experiment for the decision to implement RouteLint on a national level. For the involved train drivers, this was rather a firm change. Namely the education and the change in the train cab. When the business case was not the success hoped for and the experimental project was stopped, it was difficult for the train drivers to grasp because it looked like an actual implementation of software. They became attached to the system during the experimental project.

The energy saving that was required for the business case was not met. This business case was setup by the steering group focused on aspects like punctuality, energy saving and overall rail capacity. As operator, we had to prove that safety was not compromised (that it was not a distraction to the train driver), that the required energy saving of 3,5% was met and that punctuality was improved.

Who was responsible for stopping the project?

The NS part of the steering group. They had this conclusion as consequence that the corresponding costs did not outweigh the benefits of RouteLint according to the experiment.

Why were the users (such as train drivers) attached to the innovation RouteLint

There were a few reasons:

- As driver, you could “see” the situation behind a few signals. In other words, you have information (occupation and track- and train state) about multiple sections ahead. It makes it easier to operate in anticipation of coming situations. This is also good for travel comfort. However, this was not added to the business case because it was difficult to quantify. Besides it is pleasant for the workflow as train driver.
- The user interface was made with the train drivers themselves. They stood central throughout the process. It is a very simple user interface which allowed easy understanding.
- An enthusiastic group of ambassadors that stood for the product. Besides, a small clip was made early on that visualized RouteLint as an innovation. This clip is shown everywhere.

Why is the project stopped instead of further developing the software?

During the same time another method was developed to increase energy efficiency. This method was very simple and easy to implement. Train drivers got a card which gave information about the track. No IT was necessary. This card was developed by train drivers themselves which provided information about the point where traction can be turned off which allowed the train to be moved by its momentum until it stops exactly where it is supposed to, like a train station.

With RouteLint, the IT was a difficult part. Especially the communication between track and trainside equipment. Some examples of problems were the coverage of the network and coverage in tunnels. The IT sources were in that time also busy with updating traveller information systems during a difficult winter.

While the both options were developed simultaneously, it was not intentional by NS to compare the two options. It was not setup as a competition between innovations. For RouteLint it was just bad luck that this simple method for energy saving was introduced during the same period as RouteLint itself.

Were there any changes during the implementation?

Not from it was introduced until 2010. No changes in the visualization for the train driver were necessary. Some very minor changes such as the insertion in the Railpocket with a corresponding arrow that let you return to the main menu was added. But nothing more.

The user interface was made with train drivers. From day one the cooperation was sought with train drivers in creating this innovation. This was ideal, because this made sure that adaptability of the system was not required as much.

If there were any changes with equipment trackside is unknown for me.

There was a MVP (minimum viable product) which did not show information about preceding trains. However, train drivers were not enthusiastic about this product. RouteLint was excellent in knowing the location of other trains.

Did NS had the possibility to change the product?

NS did never ask for a change. But were able to change the product in the cab. How RouteLint was visualized for instance. The other parts were a cooperation between stakeholders. If NS would have chosen for a tablet instead of the Railpocket, then the other stakeholders would have cooperated to make this happen.

How is the structure of the product?

The RouteLint application is based on ICT sources of ProRail. It is a rather uncoupled system. The visualization in the cab can be altered independent of the ProRail systems. Also the system you used for visualizing it to the train driver. You had no influence on the source, ProRail VL (Verkeersleiding / traffic management).

What were issues from this structure?

ProRail VL named track sections in a specific manner. For some of these sections, during education, NS train drivers are learned different names. This was an awkward situation. Especially if the train controller calls the train driver about a specific section, you must communicate about the same section. A translation table was not allowed. Thus, the names used by ProRail VL are the norm.

What was the reaction when NS stopped the project?

The main response was disappointment. However, this reaction was shared throughout the project. Also with the involved employees of NS.

Appendix F.15 – Interview Manager Translink on OV-Chipcard (Summary)

Subject	Adaptability of the OV-Chipcard implementation
Respondent	Anonymous
Function	Past: Manager Consortium East-West (Accenture, Thales, Vialis, MTRC) Current: Manager Translink
Date of interview	29 April 2020
Date of verification	23 June 2020
Location	By phone

Important notions of the interview

- Translink served as centralized leader which represented around 80% of the public transport sector.
- A lot of effort went into an agreement scheme which sets the environment for the many involved actors to work on implementing the Dutch travel card.
- By specifying the request as "multi-vendor", Translink made sure that the technical solution provided by the consortium would be open in such a way that suppliers could connect to the constructed system after its realization.
- The bidding party must prove that its solution was working and was made according to the "multi-vendor" request. After this, liabilities were conveyed to Translink.
- The contract had a structure where it started with only one area. Dependent on the success of the implementation in this area, more areas were added.
- Involvement from the Ministry was minor, any investments were made during the period where dual systems were operational.
- The architecture used was based strongly upon the system implemented in Hong Kong and was fully proposed by the consortium.
- Every involved stakeholder was represented by a director in a team that made choices during the implementation. This group worked together a lot with transparency and a focus on aligning goals. When quality was experiences low during launch, this team came together to discuss the next steps instead of pointing fingers.

How was the project organized?

With the chip card, we have introduced a new payment system for Dutch public transport. This process was done in an elaborate ecosystem of different roles. The roles have worked together in an agreement scheme. A lot of effort was put into the scheme of this ecosystem. To know which roles were connected to which tasks. Especially in the Netherlands this proved important, you have various roles of the operators that run in a certain area. Some operators are responsible for revenue, in some cases you have decentralized governments that are responsible for this. In the latter, operators are just a managing party. This has an impact on the agreement scheme that is required to handle changes. If the scheme is setup very tight, in responsibilities you have, you cannot handle changes very well because cooperation is not stimulated. The governance must setup right, the technicalities will follow.

Translink was setup by five operators, NS, GVB, HTM, RET and Connexxion. Translink therefore consisted of around 80% of the market and created with this the market standard. These parties agreed together that a system must be acquired that supported all roles in the system. Translink has a business role throughout the project: a clearing and settlement party, the card producer and float owner. They are scheme manager, thus composing and regulation of the agreements themselves. Furthermore, they were manager of the technical interfaces in the system. Expectations of the various parties must be matched. Translink put a lot of effort in the organization of the market. Which parties are stakeholders. Which relations do they have between them. This stood at the base of the constructed agreement scheme.

There were various starting points in the project. One of these was; *do we have the different roles and responsibilities in the system within view*? Another starting point was the so called "Multi-vendor" request. Multiple marked parties must be able to bid on the standard throughout the systems lifetime. The request was formulated on two A4 papers where they specified requirements. Thus, on the one hand, it delivered 80% of the market. On the other hand, it must be a multi-vendor solution. Thus making sure that other suppliers can connect to the constructed system.

The supplier, the consortium, wrote the entire technical solution within this scheme. Translink, as client in the process, wrote nothing about technicalities in their request. The consortium, east-west, consisted of Accenture, Thales, Vialis and MTRC. The liabilities were taken over from the consortium to Translink when the consortium had proven that the solution was working and was multi-vendor.

The Ministry was responsible for the public transport system and did minor investments in the system. But the operators established Translink and did the basic investment. There was a business case for the system. NS, for example, had a fund (FENS – Fonds Eenmalige bijdrage Nederlandse Spoorwegen) which is partly allocated to the chip card. For city operators like GVB and RET, the closing of metro station with gates using the chip card was a business case on its own due to many people riding the metro without a ticket. The Ministry was only responsible for legally anchoring the card as travel permit. The minor investments of governments were mainly during the dual period where both systems were operating, thus requiring double cost.

Did any standards were used?

The system itself came out of Hong Kong. The Octopus card system. It worked with multiple levels. Level 0 to 4, with the card itself being level 0 and level 4 being the back office positioned at Translink. Level 3 to 1 is positioned at the operators themselves with a system of their choice. This was the technical architecture that was chosen from the first day. Within this architecture various choices can be made without losing interoperability. The whole system delivered to the public transport sector in the Netherlands, already existed in Hong Kong. Accenture, as a knowledge dense party, made the translation towards the Dutch ecosystem.

Were there any developments after implementation

In Hong Kong, you load money on a card and you pay as you go. In the Netherlands, we have a system, where the different operators can determine their own tariffs and subscriptions. Thus, the whole paper world is made electronic. This made the system more expensive and heavier than the one in Hong Kong because, while in the Netherlands around 50% is balance based, also 50% is based on products developed currently or earlier during the legacy paper system. The developments which were necessary led to a long completion time. For instance, it costed NS around 10 years after start of implementation to close down the last station with gates.

What are future developments?

There are plans for a sequel to the chip card. This is done in the "Werkprogramma OV-betalen" (work program PT-payment). In this sequel, the calculations are done in a centralized system positioned at Translink instead of doing this in the individual gates. A cloud based solution. This makes it more adaptive. Or more than the current situation where a change meant that every gate or device (around 35.000) throughout the Netherlands must be updated. In the future, you have only one centralized device. This is a solution brought in from the application world.

Does the old solution prove adaptable towards this new solution?

This is going rather well. This new innovation is supported by all operators in the Netherlands instead of only the original five. Because of this, the number of discussions required are minimized. Focus can be on the technicalities of the project.

How was leadership organized throughout the project?

Translink directed the program and managed the tender. Besides, the consortium had contracts with the various operators and Translink itself. This was done in a coordination contract, thus the various parties were obligated to work together. Furthermore, there was a management meeting with directors of the various companies together.

Was there trust between parties?

Yes, trust is very important for a project as this. With this project, especially the different directors required transparency from each other. Furthermore, to stimulate this, various trips to Hong Kong were organized. This gave bonding between directors. Transparency, alignment of goals and experiences was very important.

Do you have an example of this?

The Rotterdam area was chosen where the first launch is planned. The quality of the equipment before this phase was not according to expectation. We really had a quality problem, which could lead to pointing fingers. You must find each other before you open the system to the public.

In time, the directors had a meeting to find agreement. The consequence of this problem was too large for only one party to handle. Thus, it required cooperation to handle this. This happened multiple times in this project.

How does this multi-vendor request work and why is this requested?

In this industry, you have various parties that supply vertically integrated solutions. From level 0 to level 4. In London for instance, you have the Oyster system which is provided by one supplier: Cubic Transportation Systems. Nothing can be added. Total cost of ownership is rather large due to the monopoly Cubic has.

This is something Translink did not want. Thus, an explicit requirement was added that the solution must be multi-vendor. If the consortium did not prove that the provided system was constructed with this requirement, the liabilities stayed with the consortium. This was a very important requirement that was clear from the start.

The consortium had the freedom to design this standard, thus having all possibilities that it was going to work as a solution.

How was the tender setup?

The Rotterdam Area was the starting area. Further areas were added dependent on the success of the earlier implementation in the previous area. This was added to the scope of the contract. It became important for the consortium to work hard from start to end. If the success of the implementation did not meet expectations, then the project would be likely to start over again and the standard would be transferred in ownership to Translink.

Final Remarks

New technologies and agile working method are a big stimulant in working adaptable. This is the future. It is important to add this to the request.

Appendix F.16 – Interview Niek Govers on OV-Chipcard (Summary)

Subject	Adaptability of the OV-Chipcard implementation
Respondent	Niek Govers
Function	Past: Integration Architect OV-Chipcard Connexxion Past: Business Architect TLS Current: Integration architect Program ERTMS
Date of interview	05 June 2020
Date of verification	09 June 2020
Location	By phone

Important notions of the interview

- There were three reasons the OV-Chipcard was introduced. Firstly, budget came available partly due to the sale of World Online by NS. Secondly, the strip card became outdated due to changing desires of local governments. Thirdly, the desire to close off stations grew.
- A small group of operators that hold a large percentage of the public transport sector established Translink to tender the request for a new ticketing system.
- NS was a large shareholder during the process which allowed them to have a large influence on the way the OV-Chipcard was implemented.
- The tender was intended to be a multi-vendor proposition in the end, which required the bidder to release the specifications to the public after delivery. This allowed other parties to connect to the system once implemented.
- Each check-in/out point is connected to the entire system using cables or daily upload due to offline operation. Updating the system requires thus a complex systems management process.

What were reasons for the introduction of the Dutch smart travel card?

The start of the card came from the availability of budget partly due to the sale of “World online” by NS. As the ministry of Finance is the (only) shareholder of NS, NS was required to transfer this money gained with this sale to the Ministry of Finance. However, they made a deal where NS could use the money to invest this in the public transport sector.

Another reason was that the used strip card became more and more outdated. This was due to the fact that local governments wanted to get more involved in ticket pricing, to allow propositions targeting different groups of travellers.

The final reason was that there were large incidents during ticket control. There were several cases of serious molest of a train guards. This led to the desire to close off stations and public transport for people that did not buy a ticket.

The bus was relative quick in their implementation, the metro was more difficult. The most challenging was the implementation throughout the national train network.

How was the governance surrounding the implementation of the OV-Chipcard?

At start, there were around 17 public transport operators in the Netherlands. To align all these operators was very difficult. A smaller group of operators (NS, RET, GVB, HTM and Connexxion) took the lead in consent of the others. They represent a large percentage of the public transport sector. These parties made agreements on investments and the planning. The implementation was done only with private investments, not with direct governmental subsidies. From the start a national payment system was envisioned.

Because there was an obligation to tender this E-ticketing system, Translink was established. During that time, Translink was not envisioned to carry out various tasks surrounding the new travel solution. A consortium that bid on this tender created a copy from a system out of Hong Kong.

It started as an pilot initiative in the surrounding Rotterdam area, with the various modalities of the involved shareholders. A copy of the Hong Kong setting was brought to the Netherlands as experiment. During this pilot, organizational steps were made and the role of Translink became more clear. One of these things was to get other public transport operators on-board the process and governance. However, while multiple operators became more and more involved NS stayed main shareholder due to their large investment early in the process.

Ultimately this all led to a governance where all technicalities go through Translink and all public transport operators have an equal influence on the E-ticketing system. All requirements and desires are described extensively in a model where each of the operators can influence accordingly to their position. This reorganization took three years where standing shareholders were required to hand over influence to newly introduced shareholders.

Is there an example of a case where a change was required?

There were various discussions between shareholders. For example, NS wanted to integrate all existing paper tickets, such as the one-way or return tickets, to the electronic system. However, the original system in Hong Kong was designed as a "specification white travelling " instead of pre-specified travelling.

It took a while to align stakeholders involved to implement the E-ticketing propositions in a way which would more represent the future use. The technical system required for this change would be difficult to establish. However, after a discussion between directors of the shareholders it was agreed that this would not be a part of the system. Clear reasoning was required which ultimately led to agreement.

While NS was a large shareholder and brought the investment, they did not always get their way. How does that work in the governance?

At the start of the process the governance model was not extensively described. If a change was required to put through, it was discussed on a project basis. At the start, the different roles were not as well thought out as it currently is. During this time, Translink consisted of 10 to 15 employees with another 5 to 10 employees of public transport operators which were involved. So, it was a very small group that made the decisions.

This changed in the future where it became a transparent and orderly process where an impact analysis is executed, the business cases are researched and the change is put through.

Was the Ministry involved during the process?

The Ministry was all right with it that the OV-Chipcard was implemented by the market, the Transport operators themselves. The card must be inserted in legislation. This task was off course achieved in good cooperation with the Ministry. Furthermore, later in the process a department of the Ministry was involved in pricing and quality related issues.

However - to illustrate the difference in responsibilities - when for example the privacy related issues arose surrounding the OV-Chipcard, the Secretary of State responded in parliament that she was not responsible for the implementation and that the involved companies must come up with a solution.

The request of Translink was Multi-vendor, what where your thoughts about this concept?

This request specified that the OV-Chipcard architecture and technicalities are made public after delivery. This was done so that other vendors could connect to the system with their own product.

Within the consortium, mainly Thales constructed the specifications for the OV-Chipcard. Part of the contract was to publish the E-ticketing specifications (especially the inter connection constraints known as the SDOA). And so it happened, the specifications were made public.

Was it conceived as beneficial that Translink was setup as a separate company?

This choice was necessary. This provided the environment were all involved shareholders could have their say in the matter. Furthermore, this made national implementation easier.

The transition towards the OV-Chipcard has a very large impact on the involved companies. Starting as a “tender vehicle” Translink evolved to a full service scheme provider, card issuer and back office operator.

At first, the founding fathers took their influence to have their say in various choices in the process. Later on, all other transport operators had to join and adapt the E-ticketing system. This was a complex struggle where various steps have been taken, resulting in a stable and accepted governance nowadays.

Not all design issues are yet resolved. For instance, every operator has their own customer service on OV-Chipcard issues while Translink also has a customer service. The user must know who to call with what problem. This is not a clear custom focused situation.

It is implemented as decentral system. How easy is updating of the system?

This is a fundamental architectural choice. The card is carrier of travel information, the check-in point. This data is required at the check-out point to calculate the price. This is an offline concept. This was required for the busses and trams, because they do not have – by design – a real time connection to any back office. These vehicles have a check-in point per vehicle which moves about.

This is technique of 20 years ago. So each system in each check-in/out point works with cables or offline. No reliable airborne network could be established at that time in the Netherlands. At the start, each bus, for example, would operate offline for a day after which it would be read in the garage. Furthermore, a change in the software must also be done in the garage with cables.

Future development will me more focused on identifying the traveller and calculate a “best price” in the back office. The installed base of technical devices and infrastructure can be partly re-used an on top of that this new way of E-ticketing architecture can be realized.

Appendix F.17 – Interview Erik Voltman on OV-Chipcard (Summary)

Subject	Adaptability of the OV-Chipcard implementation
Respondent	Erik Voltman
Function	Contract manager OV-Chipcard of NS
Date of interview	01 July 2020
Date of verification	02 July 2020
Location	By phone

Important notions of the interview

- The migration to another payment system is critically vulnerable for NS.
    - The whole company is involved and affected in some way.
    - The system functions as cash register for NS. Safety and accuracy is important.
- So NS had to implement this system very carefully that resulted in delay
- Other parties could not continue the implementation without NS as largest operator
- Finding agreement in the scheme of stakeholders was difficult. This is due to differences between stakeholders and their share in TLS and to the fact that operators were competitors of one another.

When were you involved during the implementation of the OV-Chipcard?

From 2006 onwards, I was contract manager for the OV-Chipcard at the Dutch Railways during the entire project phase until 2014. I was involved in the project to function as contractmanager & stakeholder manager. Nowadays, I am working as contract manager at NS IT Group in the commercial department which includes the OV-Chipcard payment system.

How was NS involved in the establishment of the new payment system

The concession for the new payment system was won by the consortium East-West that consisted of Accenture, a French company Thales, and a Dutch maintenance organization Vialis that led to a "turnkey" agreement in 2003. My role as stakeholder manager was to bring parties together which was difficult from time to time. It was a project that involved parties of different countries and involved lots of money that came from a specific fund (FENS – Fonds Eenmalige bijdrage Nederlandse Spoorwegen). In 2007, full system acceptance was given by NS.

The migration towards a new payment system was a critically vulnerable process for NS. It functions as the cash register, so it must be 100% secure and accurate in operation. NS is very dependent on this. Because NS had various special tickets available (such as a train pass for a bike or a dog) in the paper world, some decision makers were in favour to implement all these type of products into the new payment system. East-West had to convince NS that the payment system was technically based on "specify while travelling" due to the structure of the technique. This gave friction within the project group. Friction and different opinions within the steering committee on the project became extra complicated due to the cultural differences between members. The process of alignment took considerable time.

Furthermore, NS required a long time for implementation due to the education of their staff. It had a large impact on the processes, models and operation of NS. The company was completely based on handling paper ticket world instead of its digital successor. An example is that the project experienced a delay of multiple years due NS dealing with opposition with train conductors to this innovation, the necessary education and changes in processes

All this had to be changed in the migration towards an electronic system.

NS had closed a turnkey contract with the consortium East-West, as did 4 other public transport operators, to introduce and implement a nationwide, interoperable payment system in the public transport network.

What is the structure of TLS and cooperation of stakeholders?

In the original structure, you had public transport operators that were shareholders and were non-shareholders of TLS all involved as stakeholder. The original shareholders consisted of five operators. The difficulty to reach agreement is that shareholders and non-shareholders were basically always opposed to each other. An example of this is the determined transaction fee that is used by TLS to cover their cost for the use of the OV-Chipcard. Non-shareholders argued for a lower fee and shareholders argued for a fee which was also beneficial to shareholder value.

Furthermore, operators are competitors of each other. Thus, if a change is required throughout the payment system, who is financially responsible for what? Are the desires by one party identical to the other? This led to many discussions.

NS and ProRail invested the FENS fund in the payment system. What was the effect to their position?

This fund, acquired through the sale of a cable network, belonged to ProRail & NS and was invested in the public transport sector in accordance to agreements with the Dutch Ministry of Transport. The funding itself did not change the position of NS. However, NS is the largest operator, operating on the main rail network. Other parties are likely to follow if NS chooses a direction.

The complexity of the system itself, the software implementation, the political debates all together resulted a delay of several years. Meanwhile various additional problems arose on the entire project, such as security issues, which demanded extra – not budgeted - financing to fix. This resulted in questions on financial responsibilities that led to discussion. Due to the standing of NS as larger party, other parties usually waited for NS to deal with the issues first. These parties could not continue the process without their largest operator. Another example on a typical NS problem, was the initial fee. In the original system design, it could automatically happen that a mother and four children must pay hundred euro just for checking in. For this reason, politics got involved and NS was asked to fix this problem. However, this problem was rooted in the entire system right down to the systems of TLS. The fix took various months which required other parties to wait. In the meantime NS took over the shares from a colleague transport organization which created a potential danger that TLS could be seen as subsidiary of NS, however it was meant as an standalone organization.

Around 2012, a clean slate was required between stakeholders. The Ministry provided a partial financial compensation for the original investment for the shareholder members of TLS in order for these parties to hand in their share so that all public transport operators and other stakeholders were included.

What was the role of the Ministry?

The Ministry could have played a more important role in this process by establishing central leadership and guide lining. The awareness that every stakeholder could be checked and controlled by such leader, was absent. Therefore, it was difficult to insert changeability or adaptiveness, because parties were usually opposed instead of aligned. In a more firm role I am sure that The Ministry could have pushed the project to a more productive tempo, especially on the stakeholder management side.

For me, in my position as contract manager, it was a highly demanding task to establish progress with the various decentralized governments in a multi stakeholders environment. It was also very interesting phase in my career with a big learning curve. The Ministry could have helped in this case.

Appendix F.18 – Interview Marco Kartman on OV-Chipcard (Summary)

Subject	Adaptability of the OV-Chipcard implementation
Respondent	Marco Kartman
Function	Business Innovator at Translink
Date of interview	02 July 2020
Date of verification	03 July 2020
Location	By phone

Important notions of the interview

- While the "multi-vendor" request neutralizes the possibility for a vendor lock-in, it resulted in a higher summed amount of development costs for Dutch operators.
- The new payment system requires the removal, implementation or replacement of various technical components due to the required confirmation to legislation that is applicable to the software this new system uses.
- The small pilot in Rotterdam allowed detection and fixing of early issues.

What was your role during the implementation of the OV-Chipcard?

I started working at Translink in 2004. That was before the start of the pilot in Rotterdam. Before that, I worked at NS. My primary task was managing the production and distribution of the card itself. Currently, I am working on the migration to another payment method. Specifically the architecture required in this new system.

How does this new payment method work?

This mainly consists of migrating from a closed loop system, which only allows usage within the public transport sector, to the EMV contactless technology to allow payment with (debit and credit) card, phones and other objects that support this technology. However, because these objects are difficult to check by, for instance, a train conductor, another closed loop variant based on this technology will be provided that does not contain data, like its predecessor, but has a connection to a centralized system in the back office of Translink.

Is the current system, the OV-Chipcard, adaptable towards this new payment system?

The current OV-Chipcard is based on the payment system in Hong Kong and is requested in a manner that enforced independency to its original supplier to neutralize the risk of vendor lock-in. Thus, requesting an open architecture for other suppliers to connect with. This construct had several challenges. Because of the open architecture, operates acquired the system from different suppliers. Each supplier required corresponding development costs and lead times. Thus, increasing the summed amount of development costs and lead times for all operations in the Netherlands.

The new system will be gradually introduced and implemented. However, the legacy system must be fully replaced and removed as soon as possible because maintaining two systems is expensive. Both systems are fundamentally different. The gathered knowledge by the legacy system can be used again. However, many technical components must be added, removed or replaced. One of the reasons for this is additional legislation. EMV technology must comply to international card industry safety regulations, the OV-Chipcard was, with respect to legislation, more flexible.

What are examples of changes that were necessary during or after the pilot in Rotterdam?

The operators agreed to start the implementation relatively small to detect and fix early issues. The RET, as operator from Rotterdam, suggested to start in Rotterdam. In Rotterdam, various issues arose that were not a problem in Hong Kong, but were different in the Netherlands. Examples are:

- If an OV-Chipcard was required for a customer in Rotterdam, the request was given to RET. This request was then given to Translink where the card was acquired and distributed back to RET which, in turn, gave it to the customer. This was changed towards a system where the request went directly to Translink and the card was sent directly to the customer.
- Different operators used a personalized card for their city or transport mode but because of shortage in chips necessary in the card, it was changed towards a generic card without branding.
- The security of the software used by the chip, called MIFARE, was not as secure as required. A security improvement was necessary. Every card required a new chip which resulted in a cumbersome intervention.
- The card allows automatic charging. However, to acquire this, a customer was originally required to physically identify him or herself at a counter. However, in less dense areas, this was not feasible. The process of acquiring automatic charging on the card was changed.

The consortium East-West received the concession to implement the new payment system throughout the Netherlands which started in Rotterdam.

These are rather structural changes you mentioned. How was cooperation between the operators and the consortium?

There has been a lot of discussion about the changes. There were various aspects captured in the contract that were later removed due to various reasons. One of them was that the consortium could not deliver what was needed. For example, the production of the card and service provision was part of the contract. However, these tasks were removed from the contract and added to the tasks of Translink. These tasks are done by Translink up until this day.

Appendix F.19 – Interview Ernst Cramer on position ERTMS program (Summary)

Subject	Position of ERTMS program
Respondent	Ernst Cramer
Function	Stakeholder management ERTMS of NS
Date of interview	09 June 2020
Date of verification	25 June 2020
Location	By phone

Important notions of the interview

- The positioning of the ERTMS program with ProRail instead of an independent party is considered to decrease the adaptability of the implementation process, with respect to the addition of new components. This is mostly due to the two different hats ProRail currently is required to wear as program manager as constructor of the ERTMS trackside.
- The sector was initially envisioned to be involved in the ERTMS program. It is argued that the program is a sector-driven process. However, most of its employees are from ProRail.
- Modularity is of utmost importance. For instance in the utilization of FRMCS.
- Adaptability requires a mindset of a continuously changing system which proves to be difficult for parties involved (Ministry, ProRail and NS). For NS it is difficult to change the workflow of their train drivers.
- To improve the capacity and speed of the railway network, an integrated approach is required from all parties. It is not achieved by only forcing NS to acquire faster trains.

How is the positioning of the ERTMS program conceived by stakeholders?

The positioning of the ERTMS program with ProRail instead of an independent party is considered to decrease the adaptability of the implementation process, with respect to the addition of new components. This is recognized by all stakeholders within current developments.

How is the governance organized of the Dutch ERTMS program?

Denmark chose for a governance where an independent party, a large engineering company, led the implementation process. While the first results were promising, it resulted in various issues when all parts of ERTMS came together. Banedanmark (IM) was internally not well connected between departments resulting in various mismatches and the largest railway undertaking of Denmark (Danske Statsbaner) did not feel partner of the project. In other words, when the independent party wanted to start the tender, they were confronted with resistance from the other involved companies.

With this example in mind, we started the program with the mindset that the sector must be a part of the program. I think this was well established at the start. The Ministry, ProRail and NS were program partners and other stakeholders were actively included in the process.

What happened then?

When we got into the realization phase, a successor party was chosen to do this phase. I personally think that the Ministry was the designated party that should do this, however the Ministry found this too complex due to the two functions they then would have to fulfil. This would be the role of a client and the role as responsible for realization. However, when ProRail was given the task. They would have a similar problem of having two different functions. NS argued for a similar system as the Directorate-General for Public works and Water Management (Rijkswaterstaat).

Is this conceived as adaptable?

The Achilles heel of this construction is its adaptability. The ERTMS program management team must have free hands to cope with new developments. Of course, when such developments arise, you communicate with the most intensive stakeholders such as the infrastructure manager, the national railway undertaking and the freight operators. Each stakeholder must operate independently. However in the current situation, the CEO of ProRail is responsible for the ERTMS program as the realization of the trackside ERTMS. This gives him two hats, thus disables him to make independent choices in favour of the Ministry (the client). There have been some indications where the program was controlled by ProRail, which is a risk. It could result in choices that have been made in favour of ProRail instead of the program.

NS and the Ministry were more involved from the start. How could it happen that the program was assigned to ProRail.

In the early days, I worked in the management team of program ERTMS as NS employee. However, NS left the program ERTMS after a choice from ProRail which took over the program. While it is presented as a sector-wide program, a very high percentage of employees are from ProRail.

NS stands positive to a more controlling role in the ERTMS program. A few years ago, NS was more of a resisting factor. However, this is changed throughout the years. They will carry necessary risks if needed. For example, the transition towards FRMCS or the transition towards 3kV. You cannot operate on 160 km/h without the transition towards 3kV. It is not a decision between innovations.

What was the reaction of NS when the ERTMS program was assigned to ProRail?

I am not sure. I was operational at the program management team. Personally, I think that ProRail lobbied extensively at the Ministry to keep control over the rail network. NS did not think that they must be leading this program because they have a specific operational task. However, NS does have the technical knowledge on their trains and would like to be more involved.

NS wanted to stay within the program. For me personally there was no more room in the management team. My observation is that stakeholders are not involved as much as during the earlier days of the program. For instance, the financing of train equipment is currently a cumbersome process.

How is the transition towards FRMCS, or any other innovation, conceived by NS?

It is important to introduce modularity in the system structure. I conceive this as the most threatening risk of the ERTMS implementation; the absence of modularity. Every supplier delivers a total package where ERTMS is an integrated part of the IT component of the train. Due to this reason, when you introduce a change in the on-board equipment of a train, you must accept and allow the entire train again on its network.

For instance, when one country changes something in the trackside ERTMS, for instance another baseline, and you change your rolling stock to be compatible with this change then ILT expects that you demonstrate that this change still complies with the Dutch safety levels. In short, for one change in Switzerland you must recertify the trains in four or possibly even five other countries (Netherlands, Germany, Italy, Switzerland and possibly Belgium) due to its corresponding TEN-T corridor (Rhine-Alpine). The acceptance of a train type is around 150.000 euro. This is especially unacceptable for freight operators. Every country has their own changes they want to put through in the coming years.

Thus, unity and the ability to adapt in the ERTMS system is off utmost importance. The input and output of all SIL-4 components must be standardised so “plug-and-play” is possible.

For NS, especially the transition to FRMCS is cumbersome. The tender for trains is expected next year with GSM-R. This is before the new ERA release of TSI, where the FRMCS is introduced in ERTMS. So it is probable that we must change train components within a rather short time period after delivery.

Is the desire to have a modular system being hindered by the fact that the ERTMS program is assigned to ProRail?

No, that is not the case. The program management team is responsible to extensively argue how to implement changes in the program. So, that is covered.

Adaptability requires a mindset of a continuously changing system. This is difficult in a political aspect for the Ministry and an operational/technological aspect for ProRail and NS.

The transition towards Hybrid Level 3 allows ProRail to decrease their trackside equipment, however it requires NS to implement a TIM. How is this conceived?

The knowledge on ERTMS in the management level of NS is limited. The choices made to go with certain developments are based on discussions, not based on seeing opportunities in technologies. For Hybrid Level 3, a small group in ProRail is lobbying for this technology convincing the management teams of ProRail and NS.

However, with respect to hybrid level 3, the trains of NS can transmit train integrity. Currently, this is not enabled because the trackside receiver cannot process this data. NS is a supporter of the TIM. The longest train that is allowed is 800 meter. Most trains are 200 meter. If trains can operate using virtual block sections then we can achieve a higher capacity.

It is important for the Ministry to see these opportunities and aligning stakeholders to achieve these things. NS is forced to acquire trains that can operate on 200 km/h (ICNG). There is no one that forces ProRail to improve their track in such a way that operation with 200 km/h is actually possible. If asked, ProRail would answer that it is not part of the BOV-reeks (Beheer, onderhoud en vervanging). The provided yearly budget for management, maintenance and renewing of the track. ProRail would argue that they would need more money for this improvement. However, to acquire the promised capacity and speed improvements of the rail, investments must be made in remediation of the soil and transitioning to 3kV. Otherwise, ERTMS is just a very expensive replacement for the current ATB system.

There must be enough knowledge about the system at the Ministry to function as adequate counterpart to the infrastructure manager.

How should the program be assigned to improve adaptability?

It amazes me that the Ministry did not have questions about the percentage of ProRail employees on the program ERTMS, while its management team argue that is a sector driven process. Or, that the program director is asked about the mix of employees of various companies in his management team.

Is NS eager to implement changes in the process?

We must consider the workflow for our train drivers. For instance, ATO has a high impact. There is a gap between education for train drivers compared to developing technicalities. Actually driving according to a certain ETCS braking curve is different in practice than it is prescribed in theory. To follow the trends require a lot of effort from the train drivers.

Does NS feel as a partner of the program and part of the implementation of ERTMS?

Yes. NS is responsible for operation of the railway network and is expected to change rolling stock according to the specification of the program. Thus NS feels part of the implementation of ERTMS. The new trains ordered are going to include ERTMS. However, this is only a small component of the entire train. There is some discussion about the responsibilities of NS and the program ERTMS what is part of ERTMS and what is not part of ERTMS and therefore not within the scope of the program ERTMS.

Appendix F.20 – Interview Hugo Thomassen on position ERTMS program (Summary)

Subject	Position of ERTMS program
Respondent	Hugo Thomassen, on personal title
Function	Former Program manager ERTMS Ministry of Infrastructure and Water Management
Date of interview	17 June 2020
Date of verification	25 June 2020
Location	By phone

Important notions of the interview

- The ERTMS program was for the plan study phase originally established by NS, ProRail and Min I&W as equal partners which led to a governance based on consensus without binding of each of the partners which delayed the process and led to avoidance in big design choices.
- ProRail was in face of the upcoming realization phase commissioned by Min I&W as vessel to integrate the system due to their expertise, the ability to overlook the entire system and their familiarity on such tasks.
- This two-fold task of ProRail (directing the whole and implementing infrastructure) can lead to the principle-agent problem where the ERTMS program could make decisions based upon the interests of ProRail
- Min I&W must as principal and responsible for system integration of the railways perform checks and balances. However, this requires an adequate amount of knowledge and technical resources. The policy of the way of sourcing is changing within I&W and is being filled in differently for different system integration programs. This diffuse situation risks to enlarge the principal-agent problem.

Why is the ERTMS program positioned to ProRail?

In the early days of ERTMS, no Dutch stakeholder wanted to migrate towards it. Attje Kuiken and her committee argued in 2011 for an adoption of ERTMS in the Netherlands. However, the Ministry, ProRail and NS did not like this. It was mostly considered as a must. But, the choice for ERTMS was made.

These three stakeholders agreed to partner up and form the ERTMS program to work on the elaboration and planning of the ERTMS implementation. It was agreed that this process was performed while being equal partners sourcing the program organization. This agreement had its drawbacks:

- It is not entirely true that all three were equal partners because the financing came from the Ministry.
- Discussions to reach consensus took a very long time.
- Various employees of the stakeholders were posted in this program for their expertise. However, the stakeholder could distance itself from the work of this employee which had an impact on the effectiveness of the program.

I think that this diffuse governance resulted in two years delay and that big design choices were avoided. The implementation decision was taken in 2019; 8 years after the kick-off of the program.

From 2017 on, the sentiment turned towards the opinion that ERTMS was needed. ProRail realized that ATB was, in fact, becoming more outdated and NS realized that the potential capacity increase is beneficial.

When arriving into the realization phase, it was considered to continue as equal partners. However, the implementation of ERTMS was simply a system integration problem which required a change of track and trainside components plus various workflow processes. Formally, Min I&W is in charge as system integrator. However, the required knowledge is absent at Min I&W.

Other options that were considered are a structure where a contractor was hired to govern the process or an Min I&W department could be setup. Both were not preferred.

In the end, a system was chosen where the task of system integration was given to one of the market parties. This was considered the least worst option. Preferably you would establish a rail design authority for an implementation of ERTMS. However this was not done due to its complexity in policies. For instance surrounding the restructuring of ProRail becoming an independent administrative body or the concession for the main rail network.

The obvious choice for the position of such a program is ProRail. ProRail is the only party that can overlook the entire system, they are familiar with such tasks. To overcome mixing desires, independency requirements were constructed on the program management team. ProRail received two different independent tasks to perform. This construct is new in the rail sector.

This structure is similar to the Swiss structure where a so-called "Systemführerschaft" or system ownership is conveyed by the ministry to the Swiss IM, the SBB (Schweizerische Bundesbahnen or in English: Swiss Federal Railways). The SBB has the task to implement ERTMS in the entire rail sector.

What are the effects of this choice?

While I think that this positioning is the good choice, there are some drawbacks. One major drawback is the introduction of the principal-agent problem:

This definition describes a scenario where the agent can make decisions and take actions on behalf of the principle. The agent is likely to be motivated to act in their own best interest which could be contrary to the interests of the principle.

In the program ERTMS, the interest of Min I&W and ProRail is different. Additionally, there is an information dissymmetry. ProRail has much more knowledge about the ERTMS than Min I&W. In this instance, Min I&W must make decisions on the information given by ProRail. The task for Min I&W is to guard that the program ERTMS stays independent and that no through passage is made between different departments of ProRail and the program. Thus guard that the program ERTMS acts solely on the interest of ProRail.

An example of this is the potential addition of the northern lines to the ERTMS program which was desired by ProRail directors from the start; without having conducted a serious study by the program organization.

Why did the original structure not continue with some alterations in the governance?

The original structure led to much discussion because a consensus must always be reached. Choices were not made. This was improved when the program was positioned with ProRail.

What were conceived difficulties by the Ministry on the ERTMS program?

There is disagreement in Min I&W on its role. I think that Min I&W must take a more prominent role in checking the system integration of ERTMS for reasons mentioned earlier. However, this is currently not possible due to limited knowledge and technical resources at the Ministry. Others within the Ministry think that this task must be done by the sector itself. The latter could undermine the functionality of the Min I&W ERTMS program manager. This program manager must perform checks and balances and this can only be done if given this position.

In what way is the sector involved in the ERTMS program?

The sector is represented in the steering group, so it is sufficient. In the program ERTMS, there are employees that have knowledge about train equipment or freight operators. It is difficult to involve freight operators in the program. These stakeholders are bottom line thinkers. In other words, the price paid for which benefits.

Appendix F.21 – Interview Merel Remkes on Use Case (Summary)

Subject	Validation Use Case
Respondent	Merel Remkes
Function	Program manager ERTMS Ministry of Infrastructure and Water management
Date of interview	29 June 2020
Date of verification	05 July 2020
Location	By phone

Important notions of the interview

- Between a technical introduction and insertion in the ERTMS program is the political process which has its own dynamics, usually requiring long preparations, decreasing adaptability.
- Policy cannot be written only on informal interaction. (A mix of) multiple policy instruments can be used to achieve the objective, like: regulation, subsidization/loans or guarantees, providing information.
- Every action will has its own reaction. Transparency is good and necessary, but not will automatically lead to adaptability.
- Technology
  - Parties must have sufficient preparation time for new technologies.
  - Transparency about expected change could result in restraint of parties to update or upgrade today.
  - A roadmap must be established where innovations are put into time periods enabling the ability for parties to prepare and anticipate.
- Governance & stakeholder management
  - The introduction of joint KPIs on performance could also have the negative side effect of parties having restraint to innovation due to the risk of unmet standards.
  - Involvement is important. However, operators consider what they need to pay bottom-line.

Introduction Use Case

A quick change to FRMCS as suggested in the use case is very difficult. You suggest the importance of technical maturity. It could be reached in, say, one year. To effectuate policy instruments will take longer; for example it will need around two years to write and pass a new law in parliament. So it could happen that a new TSI is introduced in 2022 but it will take until at least 2025 to be neatly inserted in the implementation plans. In short, much time is needed between a technical introduction and the insertion in the program. Adaptability is therefore difficult.

ERTMS baseline management

The Ministry wants to provide enough preparation time for market parties to change towards a new state. Parties need to be able to anticipate. However in the use case, if IenW decides to use another baseline without having enough time to adapt after the original implementation, this could be seen as unreasonable and lead to problems in the sector. For this reason, The State prefers proven and steady technology.

Transparency is important, but not enough. You will need to create incentive for parties to follow decisions. Furthermore, in this special case the result of announcing such a big change could be that no freight trains will be updated anymore due a bad business case due to the continuous development. Is that what we want to achieve?

Implementing in regions is possible for the infrastructure and is a good idea. However, I cannot see it happening immediately for the trainside equipment. Freight operators and NS operate throughout the country. Trains that operate in Groningen must be able to operate in Limburg. Furthermore, due to union and political reasons it is also difficult to change this and split operation into regions. In other words, that certain trains would only be operational in certain regions. Therefore, regional tendering for trainside equipment is difficult.

Other technology

An integrated planning must be established where a route is given through the various innovations. Stakeholders must hold to this planning and must be able to depend on others to also hold to this planning. For example, if a train operator has integrated new components in its system but cannot use it for two years due to delay trackside, financial compensation could be asked.

Position program ERTMS

The goal of the establishment of the program management team is to bring balance into the stakeholder involvement. ProRail performs tasks that are requested by other parties. To bring balance into the program, it would be better to ask the right questions and have the right requests. To have this, an integrated planning would be usable.

A diversity in employees is good. However, how is this organized? And even if the diversity is stimulated and organized. It might not have the effect wanted.

Originally, it was considered to equip the program manager with a group of experts that advise the Secretary of State on developments for decision making. However, the chosen form was that ProRail performs this task, as large part of the responsibility, knowledge and tools are already in place. If IenW fulfils this task, then you would create another independent group that must be taken into account with decisions. ProRail must perform this task as overarching body and as expert. The Ministry must not perform this task; I am not a railway expert. Many years ago the Ministry consisted of more people that were specialized in certain disciplines. However, the current trend is that the ministries house mainly generalists and specialized knowledge is put with other parties.

Stakeholder involvement

All solutions here are important. Especially the first. It would create better understanding of one another. Furthermore, to involve stakeholders in a transparent manner it is necessary to have an innovation agenda, or an established plan as mentioned earlier.

The last solution, the joint KPIs, is valuable, but an innovation KPI is very difficult to compose. Furthermore, a KPI on performance could also have negative effect on innovation and changeability. Punctuality, for instance, is already introduced as joint KPI between ProRail and NS. However, on short-term this KPI leads to restraint of parties to innovate. This is due to that innovating could lead to disruption of the operation and thus result in unmet standards for punctuality. While it is good to introduce joint KPIs, be aware of the negative side effects it could have.

Changeability is difficult for establishing a positive business case. Operators mostly consider what they need to pay bottom-line. You can involve the stakeholders, but if you require them to change over and over again, you would get opposition.

Changeability in the contract

According to various contacts, in the current tender of the CSS, changeability is already inserted in the contract through partnerships and frame contracts.

More flexible policies can be inserted through the so-called Netverklaring (network statement) created by ProRail. In this document requirements can be specified on corridors and corresponding trains. Through this system you can steer policies locally. However, it is necessary that certain goals are actually met. This could result in, as mentioned earlier, financial compensation for operators if goals by the infrastructure manager are not met.

Final remarks

The government has a box of available tools that can be used. While involvement of stakeholders and alignment is important policy cannot be written on informal interaction alone; the stakes are too high.

An integrated roadmap is important to construct that clarifies in a transparent manner what the goals are, where the challenges are and where the future innovations lie. An overarching implementation strategy.

Appendix F.22 – Interview Atsert Walsweer on Use Case (Summary)

Subject	Validation Use Case
Respondent	Atsert Walsweer
Function	Legal Advisor at Ministry of Infrastructure and Water Management
Date of interview	29 June 2020
Date of verification	01 July 2020
Location	By phone

Important notions of the interview

- Not only the program manager of Min I&W must have the position to fulfil its role. All roles must function in compliance with the intended governance model.
- A dot on the horizon must be created. A given path that specifies when which corridors are addressed with what measure for stakeholders to rely on. If deviation from this path occurs, legal certainty is at stake.
- While communication is important, the Ministry could use a range of instruments. The proper and firm use of all instruments is necessary, not only with non-binding measures.

Introduction Use Case

The technological solutions given are recognizable for in the project surrounding the ERTMS implementation. My expertise is more focused on the governance and corresponding regulations. In a project like ERTMS it is important to specify responsibilities and preserve them.

Position program ERTMS

The Ministry is responsible for the system. The project leader, through the program ERTMS, is positioned at ProRail. Balance in stakeholder involvement, as these solutions want to achieve, can indeed be improved if the Ministry can adequately perform checks and balances. With this, any backroom decision-making can be avoided. However, all roles must function in compliance with the intended structure. In short, I endorse the second solution but want to extent it to all roles in the governance. So not only the program manager, but also the Secretary of State, the steering group and the program management team.

I have more restraint for the first solution that suggests a quota of various employees in the program ERTMS. It could be seen as artificial intervention. From a governmental perspective it is important to ask if this would be part of its authority and responsibility? As solution, it could help but I do not think it necessary.

Stakeholder involvement

Of course, it is important to communicate. However, the government is also required to control the process and distribution of tasks. For this, a government has various instruments for this. Examples of these instruments are regulations, obligations, agreements, subsidies and communication. For this, a dot on the horizon is needed. Boundaries and processes must be clear. If this is not the case, risks are introduced. Legal certainty is at stake, with the potential of financial compensation if parties cannot rely on the described planning. For example, it is important to describe when which corridors are addressed with what measure, that this is maintained during the process and that this is enforced. The usage of these other instruments are now missing in your solutions.

In short and following the Use Case, you will not get there with only non-binding measures and without proper and firm use of all available instruments. While the solutions include some of the measures, all are necessary. The solutions that are given are all important. Especially stimulation of cooperation and coordination with joint KPIs is very important.

Changeability in the contract

A set course must be maintained. The project must be completed at some point in time. It cannot be driven by technological developments alone. Otherwise, it would function as ungoverned body. For example, with the replacement of GSM-R to FRMCS quick after implementation could resolve in risks in legal certainty, thus the corresponding financial claims. What is an interesting emerging development for some may not be for others. This is the risk of rewarding changeability.

The risk of flexible policies, also for the given use case, is that legal certainty could be as stake. That is, if stakeholders cannot rely on the given planning and goals. Stakeholders would send financial claims for damages based on the general principles of good administration.

Appendix F.23 – Interview Daan Kers on Use Case (Summary)

Subject	Validation Use Case
Respondent	Daan Kers
Function	ERTMS Expert at Ricardo
Date of interview	29 June 2020
Date of verification	03 July 2020
Location	By phone

Important notions of the interview

- Solutions on ERTMS baseline management are endorsed with current timing.
- New innovations cannot be applied in rolling stock if official specifications are not released.
- Modularity is a mean to increase financial lifespan of on-board ERTMS and decrease price for upgrades of ERTMS. Components should be uncoupled according to their market feasibility
- An integrated roadmap of digital innovations and their effect and overlap is a condition for effective asset management of vehicles.
- ETCS in itself is not modular and has a much shorter lifespan than rolling stock
- Updating rolling stock could result in the necessity to comply to various newly introduced National Technical Rules of the countries where the rolling stock operates in. This is a hindrance for adaptability.

Introduction Use Case

With the current technology and type of contracts that correspond to ETCS vehicle equipment, adaptability is difficult to implement. ETCS is one integrated system with one corresponding supplier. This leads to a limited lifespan. A rule of thumb, one can depend on a financial lifespan of seven years and a technical lifespan of fifteen years. A strategy can be chosen where you agree with replacing equipment every seven years.

One of your solutions is inserting modularity, which is considered to impact costs of updates and replacements of equipment. This can be split between components, which is beneficial if a market does exist but is hindered. Where tension is in the market, you can use that to acquire components for a better price, though adaptability is a condition for that. As a result the financial lifespan can be increased. For replacement of ETCS in a vehicle vendor locked situation a significant price decrease can be expected.

ERTMS baseline management

Your assumption that the next set of TSI would be fully compatible, with respect to the system versions (SV), with the third TSI is indeed aligned with current plans by the European policy-makers. The head of the ERA said on consecutive versions of TSIs that they must be compatible (‘*interoperable in space and time*’) for a certain period. It is planned that the X in the SV must be aligned during a transition period ensuring interoperability between different TSI on-board and trackside equipment. However, involved experts have not concluded yet how this is actually should be achieved.

In the current situation and use case, I fully endorse the solutions given. However, they are dependent on time. Especially the definition of maturity of ERTMS specifications in a TSI is dependent on the arrival of new functionalities, such as FRMCS, during that specific time. Each of these arrivals have risks and opportunities that have an effect on ETCS.

The ERA increasingly puts effort in creating a new TSI with mature specifications for newly introduced functions, including simulation, laboratory experiments and testing on track sections by Shift2Rail and first applicants.

ETCS application level management

ETCS application level is outside the scope of the use case. But I can endorse the solutions given.

Interface management

Modularity can only be obtained if harmonized technical interface specifications are available. For instance, industries informed that enabling an interface between FRMCS and the EVC/Euroradio needs official specifications[2]. Generally, draft interface documents are considered as insufficient by industry as basis for product development.

This applies to the on-board part of CCS, which market is characterized by large numbers of customers and vehicles and where common vehicle owners initiatives are difficult to organize. Due to this fragmentation, market driven standardisation has been difficult to obtain.

Component management

An system uncoupled from FRMCS needs interface spec release. Development costs that are made by industry parties generally are allocated to the first buyers of that system. If the original system could have been tendered in a modular fashion, the FRMCS components could be separately tendered. However, in the current situation, ETCS uncoupled technologies like FRMCS in vehicles cannot successfully be tendered.

The choice for migration towards FRMCS over the enhancement of the GSM-R network depends on more factors than the one given in the proposed solutions. Like the earlier discussed solution on maturity and an asset management strategy. Against that background, I can endorse this solution.

The simulation of technological and operational choices for large scale implementation of new technologies is logical. Especially the effect of operational choices, because that is the end goal. Not the technology itself. This is a step to be taken before commercial testing in a smaller region as you specified in an earlier solution.

I advocate an integrated roadmap of the coming innovations and their effects. This roadmap could also describe the overlap and synergies between innovations.

One modular interface you did not describe in the solutions is between ERTMS and the vehicle. That one is determinative to decouple the markets for ERTMS and rolling stock.

[2] Website ERTMS-NL.nl

Certification and Acceptance

National Values are partly relevant for the system safety case, subsystems certification and authorization. This is different for National Technical Rules which do have another meaning. . If new national rules are implemented in law (called ‘notified’), existing vehicles do not have to comply to these new rules. However, once the vehicles are updated after implementation of the rules, then they have to comply. The latter is a very hindering factor for adaptability. For freight undertakings that operate in five countries, it is more difficult than for national operating fleets. For example, when a freight operator updates its rolling stock for Dutch reason, it shall have to deal with newly implemented rules in Italy.