Social Cost Benefit Analysis of implementation strategies for ERTMS in the Netherlands

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1 Introduction

1.1 Background

Legacy signalling systems prohibit the development of an integrated European railway system

Throughout the European Union, more than 20 different railway signalling and control systems are functioning today. The coexistence of these different systems is a serious problem in the development of international railway traffic. Trains crossing borders must be equipped with the various systems of the countries and regions they pass. Since the nineties of the previous century the European Commission has been funding research to develop a "European Rail Traffic Management System", ERTMS. At the time of writing, a working ERTMS package is available. However, more advanced versions are still being developed.

Meanwhile the European Union is stimulating member states to start implementing ERTMS. When investing in new high speed infrastructure ERTMS is obligatory. Also, ERTMS is a condition for getting EU subsidies for any new railway infrastructure. In the Netherlands the dedicated freight connection between the Port of Rotterdam and the German hinterland ("Betuweroute") and the high speed line from Amsterdam to Brussels and Paris ("HSL Zuid") are already equipped with ERTMS. ERTMS will also be deployed along the Amsterdam-Utrecht line in the very near future. Besides that, the Netherlands are obliged[1] to make the port of Amsterdam accessible for ERTMS trains at the latest in 2020.

1.2 ERTMS: towards a standardized European Rail Traffic Management

What is ERTMS?

Already in 1957, the treaty of Rome first mentioned a European transport policy. However no real progress is made until the 1980's. In 1980 the EU began an Common Market Programme for an integrated transportation policy, focusing on road, air and maritime transport. From the 1990's onwards, Trans-European Networks are the focus of the European Commission and the railways were given an important role. A competitive railway sector is considered a vital element in responding to transportation demand in the common market. To create such a competitive railway market the various national legacy systems for signalling and train control, have to be replaced by systems that are interoperable throughout Europe[2]. Railway experts, the industry and railway operators set out on developing such a system called ERTMS.

In 1996 the European Commission issued a directive regarding the interoperability of high speed railway lines[3]. In 2001 a directive was issued on the interoperability of conventional lines[4]. Since

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[1] European Commission decision of 22.07.2009.

[2] UIC (2009). *Compendium on ERTMS*

[3] Directive 96/48/EC of 23 July 1996 on the interoperability of the trans-European high-speed rail system.

[4] Directive 2001/16/EC of 19 March 2001 on the interoperability of the conventional rail system.

then Technical Specifications for Interoperability for Control, Command & Signalling (TSI CCS) have been issued. These directives had the objective to establish conditions that would allow cross border railway traffic without problems or technical interfaces and contribute to a European internal market for construction, operation, renewal and upgrading of the trans-European high speed and conventional railway systems.

Traditional systems rely on lineside signalling and protection systems on fixed locations being able to give only limited instructions to train drivers (the fixed maximum speed for a track section, go, brake and stop). This means that, where no signals or protection systems are in place, train operators have limited possibilities for anticipating upcoming events and therefore have no means of optimizing speed and braking. Also traffic management is not continuously aware of the exact status of tracks and trains, creating the need for buffers in the physical space and time separating trains running on the same line (the so called “blocks”). The traditional Dutch system, ATB, also has these disadvantages, although recent investment and upgrades have been made and are being made to optimize traffic management to a very high level (see also chapter 2).

ERTMS Level 2 relies on in-cab signalling and modern computer and communication technologies to monitor track occupancy/vacancy. With ERTMS, railway traffic is no longer dependent on the physical locations of signals, making it possible to shorten block lengths more easily by adding more train detection devices. The exchange of information between the train and traffic management is also more advanced: instructions van be given continuously and speed and location are known. This creates almost real time continuous monitoring allowing a far more flexible use of tracks and trains. Trackside detection is only needed to check the train integrity (is the train on the right track and is it complete). In it’s ultimate version (Level 3) ERTMS doesn’t need trackside train detection systems at all, creating even more flexibility and saving costs on the infrastructural side.

The case for ERTMS: three main reasons

With the described characteristics of ERTMS, there are three main reasons for implementing ERTMS:

1. **Interoperability.** Interoperability will enable trains to operate effectively from country to country. For this effect to take place, there has to be a real industry standard, where systems and parts can be supplied by different companies. Also, this will result in a more open, competitive industry.
2. **Capacity and performance.** ERTMS, in its ultimate form, will enable traffic management to operate without the actual restrictions of infrastructure based signalling. Eventually this is supposed to enable moving and flexible blocks, which will increase capacity and performance.
3. **Safety.** As opposed to the Dutch ATB system, with ERTMS in place, it will no longer be possible to pass signals at danger. Reducing the risk and consequences of accidents caused by these so called Signals Passed at Danger (SPAD’s), improves the safety of the railway system. ERTMS makes it also possible for track workers to control a piece of track, reducing their risks.

ERTMS implementation in the Netherlands

Throughout Europe countries are deploying current versions of ERTMS on new and sometimes existing track sections. This is also the case in the Netherlands. Since the early nineties the Dutch Railway sector is performing studies to optimize the utilization of the Dutch railway network[5], leading to the BB21 programme in the end of the 20th century[6]. Modern signalling, safety and communication systems are an important subject in these studies. ERTMS has become one of the dominant techniques in this modernization due to European legislation, interoperability and possible economies of scale. The following sections are already equipped or are being equipped with ERTMS:

- Betuweroute, the dedicated freight line, linking the Port of Rotterdam to the German hinterland (part of the Rotterdam – Genua corridor), operational with the exception of two locations ('eilanden') where the conventional ATB system functions.
- HSL-Zuid, the Dutch part of the high speed line linking Amsterdam to Brussels and Paris.
- Hanzelijn, a new line linking Lelystad and Zwolle, expected to be operational in 2012.
- Utrecht – Amsterdam, one of the busiest track sections in the Netherlands. Tracks are being fitted with ERTMS equipment next to the ATB systems (dual signalling). ERTMS functionality will become operational in 2010.

The two lines that have operational ERTMS systems are dedicated freight and high speed lines, with specific rolling stock. There is no actual experience in the Netherlands with integrating ERTMS in standard commercial services throughout the network.

1.3 Aim and scope of the study

In the Netherlands, conducting a social cost benefit analysis (SCBA) is mandatory for major infrastructure projects. A standard SCBA methodology has been developed, the so called "Overview of Impacts of Infrastructure" ("Overzicht Effecten van Infrastructuur", "OEI")[7]. This guide is also used for the analysis in this study.

1.3.1 Aim of the study

The analysis aims at evaluating two strategic options for implementing ERTMS. Starting point is the strategy that was published in 2006 by ProRail, the Dutch infrastructure manager, and was supported by main operator of passenger services NS, and the association of freight service operators (BRG, now KNV)[8]. One of the key elements of this strategy is the conversion of 100 percent of rolling

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5 For examples see background documents *Modernization of signalling systems in the early nineties* under references.

6 For examples see background documents *Modernization BB21* under references.

7 The guidelines were first published by CPB/NEI in 2000 as "Onderzoeksprogramma Economische Effecten van Infrastructuur. Leidraad voor Kosten-batenanalyse". Since then various updates and addendums have been published.

8 ProRail (2006). *Implementatiestrategie ERTMS*

stock to a hybrid system with ATB and ERTMS, before ERTMS is implemented in the infrastructure. From the House of Representatives the question arose whether this implementation strategy of ERTMS is the fastest way to reap benefits for passengers and tax payers. Possibly, an alternative strategy could collect the gains of ERTMS (interoperability, capacity, speed and safety) earlier. Decisio has been asked to clarify the differences in costs and benefits between the sectors strategy and an alternative strategy where rolling stock and infrastructure are converted simultaneously. As the ministry chooses to wait with ERTMS investments for a version becoming available in 2015, this is included in both strategies. In response to additional questions from the House of Representatives, a third strategy is included, to analyze the effects of a strategy where investments would start as soon as possible with the current versions of ERTMS equipment, needing upgrades later. The first goal of this study is to identify all costs and benefits associated with these strategies, and to assess the magnitude of the identified effects.

Another discussion is the level of government subsidy for converting rolling stock. The minister of transport promised to subsidize 50 percent of the costs of this conversion, but operators intend to convert their rolling stock only with a subsidy of 100 percent. The second goal of this SCBA is to investigate the influence of the subsidy level on the actual implementation of the strategies and to clarify the subsidy level which can be seen as fair, effective and efficient.

Research Questions

The ministry of transport asked us to answer the following questions:

1. What are the social and private costs and benefits of the implementation strategies?
2. Which effects are to be expected from two different subsidy levels (50 and 100 percent) for the conversion costs of rolling stock?
3. What are the risks of the resulting scenario's?
4. Determine the robustness of these scenario's using sensitivity analysis.
5. Which implementation strategy and which government subsidy maximizes the social cost/benefit level?

1.3.2 Scope of the study

Scope of the analysis

To answer these questions we compared the three strategies before with a so called "null" alternative. The four resulting alternatives are summarized as follows:

1. The "Null" alternative, which represents a situation where no actual implementation strategy is followed. The null alternative is used as a reference for the actual implementation strategies. In this null alternative some tracks have already been or will be equipped with ERTMS systems. And also in the null alternative ERTMS will be implemented in the long run, even if no specific strategy is followed. This study introduces also a Null+ alternative, in order to deal with uncertainties about some developments in the technique used.
2. The "Railway Sectors Strategy", in which all rolling stock is equipped with ERTMS systems first. The infrastructural conversion starts only when all rolling stock is fitted with ERTMS. In this

strategy there is no need for “dual signalling” (i.e. track sections where both ATB and ERTMS are operational at the same time).

3. A strategy of “Natural replacement”. This strategy is called “Natural replacement” because it aims at replacing existing signalling systems and fitting trains with ERTMS equipment, only when the existing systems are at the end of their technical or economical lifecycle. Another key element of this strategy is that it aims at reaping benefits for travellers and shippers from early ERTMS tracks (e.g. Amsterdam-Utrecht, Hanzelijn) as soon as possible. To use ERTMS functionalities in the short run, “dual signalling” is imperative. When there is enough rolling stock ERTMS “only” tracks become feasible.
4. A strategy that starts as soon as possible in order to make use of ERTMS functionalities as soon as possible. This strategy was introduced by the representatives Roemer and Cramer. Because this strategy requires upgrades after 2015 this strategy is called “Upgrading”. In line with the sectors strategy, all rolling stock will be ERTMS equipped first, the infrastructure investments will take place after all rolling stock is converted.

The first alternative is required by the SCBA methodology, and will be discussed in paragraph 2.2 The second alternative is identical to the strategy published by ProRail in 2006, with a single alteration: timing (waiting for the 2015 ERTMS version). The third alternative is derived specifically for the purpose of this study by the ministry of transport. The philosophy of this strategy is on the one hand to capture benefits as soon as possible and on the other that not necessarily all rolling stock and infrastructure need ERTMS functionality. The majority of investments will also start after 2015[9]. In a reactions to questions about the timing by members of the house of representatives an additional alternative is included to show the effects of starting the implementation as soon as possible with the current ERTMS version and upgrading after 2015. These strategies are discussed in paragraph 2.3.

Technical and geographical scope of the study

The difficulty with analyzing costs and benefits of ERTMS strategies is that there is no strictly defined physical “project”. ERTMS is a technical solution for existing functions in trains and infrastructure. As it is new technology it is (or at least has been) more expensive than existing technologies. However, prices are expected to fall significantly the coming years, the pace depending on the further standardization, developments in market structure and tendering procedures. In the long run, signalling systems will probably be replaced by ERTMS, regardless of any implementation strategy, but simply because this technology will be the least expensive, or because it is the best technology available for the (future) requirements of signalling structure.

This implies that in the long run ERTMS technology will also be used in the Netherlands in the null alternative. Cost of replacements of signalling equipment in infrastructure and rolling stock will con-

[9] Ministerie van Verkeer en Waterstaat (2008). VenW/DGMo-2008/4763

verge over time. But if procedures are not adapted to the possibilities of the new technology, no benefits are expected.

The fact that in the (very) long run there will be no significant technical differences in tracks and rolling stock, has implications for the cost benefit analysis. Benefits of ERTMS can probably be captured for a very long time period, however this could also be possible in the null alternative. Once enough rolling stock and infrastructure has been ERTMS equipped, procedures can be adapted to capture benefits. We therefore limit the time scope of our analysis. Usually in SCBA's an infinite time horizon is taken into account, as projects are expected to have a permanent effect relative to a null alternative. As this is not necessarily the case in this SCBA we limit the scope to a period of 40 years from the start of infrastructural investments in the "slowest" strategy[10].

For the implementation strategies we limit the (specified) investments in infrastructure and rolling stock to a period of 25 years after the first infrastructural ERTMS replacements will have taken place[11]. After that benefits are taken into account for another period of 15 years.

Furthermore the analysis is limited to the routes where most costs and benefits of ERTMS are expected to occur. The infrastructural scope of this study is on the main passenger and freight lines. Regional lines are not taken into account. In line with the sectors strategy this study focuses on approximately 2,000 km of main lines (4,800 km laid out as single track), as the major cost and benefits of ERTMS are expected to be related to these lines[12]. These lines add up to approximately 75 percent of the network. This is close to the size of the main rail network (Dutch: 'Hoofdrailnet'), which is the scope of the Level 2 implementation of the sectors implementation strategy. The scope of the ProRail business case for the Mistral programme is also 75 percent of the network.[13]

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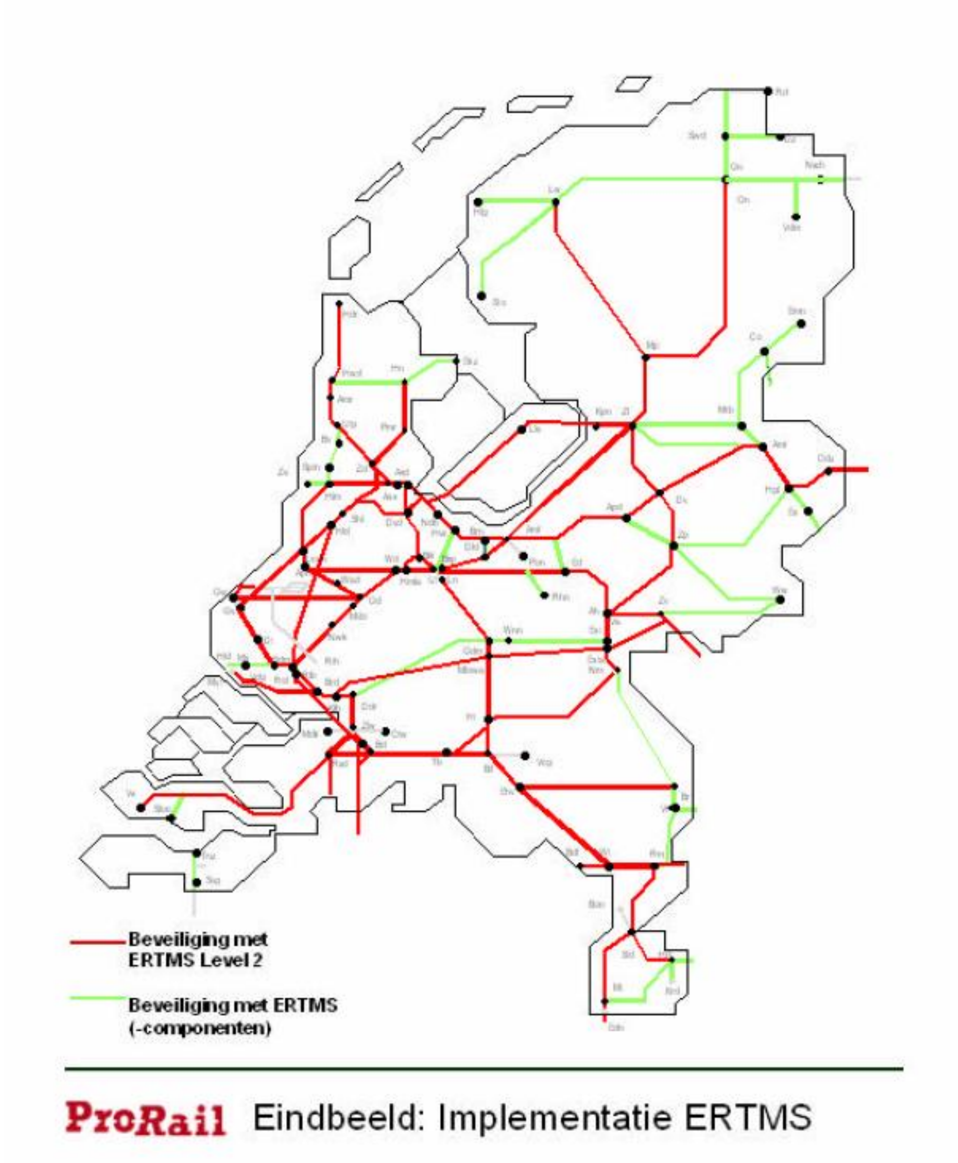
[10] This means that no differences are assumed between the implementation strategies and the null alternative after this period. The 40-year period represents a lifecycle of infrastructural investments.

[11] The 25 year period corresponds to the implementation strategy of the sector of 2006. In our analysis we assume the start to be in 2020, the end in 2045, corresponding to the period 2012 – 2037 in ProRail (2006). The implementation period is based on implementing ERTMS on approx 200 km/year. This is comparable to the Danish implementation strategy (where the exact length to be equipped is not given, but there are about 2200 km of BDK lines (excluding Copenhagen S-bane) and rollout should last 10 years). The UK strategy foresees an implementation speed of approximately 470 km/year.

[12] This does not mean ERTMS will have no effect whatsoever on regional lines. The use of ERTMS components, or the implementation of "ERTMS-regional" might be cost effective in the future, and also ERTMS testing on regional lines might be very promising. We will address this in a qualitative way in our concluding chapters.

[13] ProRail (2009). *Financiële analyse, Bijlage 1 bij Business Case Mistral.*

Figure 1.1: Geographical scope of the sectors strategy



2 Problem analysis and implementation strategies

One of the discussions among stakeholders in the Netherlands, is whether ERTMS should be implemented because of the European goals on interoperability, or because of its effects on the national railway traffic. The assumption is, that if implementing ERTMS is mandatory to comply with EU directives, there is not much choice in where and when tot invest in ERTMS. If on the other hand, there are national and regional benefits, it would be interesting to find out when and where implementing ERTMS might be worthwhile for the different parties involved. In our analysis we have assumed the latter.

2.1 Problem analysis

In 1988 a report called Rail 21 was published by the Nederlandse Spoorwegen (NS, at the time still an integrated company managing infrastructure and train services)[14]. In this report the need for additional railway capacity was signaled. Because of the extensive investment costs of physical expansions, advanced planning and traffic management was seen as a possible solution. In the following years different technical systems were looked into, amongst others ETCS (European Train Control System, an ERTMS subsystem) and new and improved versions of ATB.

In this section we discuss the main effects attributed to ERTMS, and their possible use for the Dutch situation. The effects discussed are interoperability, capacity, speed and safety[15].

2.1.1 Interoperability

The many different signalling systems that are used in Europe today, make international train operations costly and or time consuming. The high speed Thalys trains (operated on lines connecting Amsterdam, Brussels, Paris and Cologne) have a total of seven systems on board in order to be able to cross all borders. This causes high investment costs in rolling stock for international traffic. Another way to cope with the interoperability problem is to switch traction units at the border. This however causes large delays and capacity problems at the border. ERTMS is one of the measures to solve the interoperability issue. ERTMS makes it possible to increase capacity, speed and competition on international corridors. In the long term competition on national routes should also be possible.

There are however some issues regarding interoperability and ERTMS. At the moment there is no version of ERTMS which fulfils the wishes of all European countries. This implicates that there is no real standard for ERTMS. ERTMS Level 2 had for quite some time been optimized for high speed railways, but was not ready for conventional tracks and complex junctions. Countries that have im-

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14 NS (1988). *Rail 21 - sporen naar een nieuwe eeuw.*

15 In the UIC Compendium on ERTMS (UIC, 2009), interoperability, capacity and safety are mentioned as potential benefits of ERTMS. Specifically for the Dutch situation speed is also included in this study.

plemented ERTMS in some form, have made adjustments to the system causing it to be non-interoperable. Software on rolling stock with ERTMS needs to be adjusted in order to use railway tracks with ERTMS in different countries. A new version (called Baseline 3 of ERTMS L2), which should be ready in 2015, is supposed to solve the issues with the current version[16]. With this version local adjustments to the software should not be necessary.

Still, ERTMS continuously develops into newer versions. Rolling stock with an older version cannot use tracks with a newer version of ERTMS. The other way around, this problem does not exist: rolling stock is backwards compatible with older versions of ERTMS in the infrastructure (from 2.3.0.d on). For trains crossing borders, this means that they have to be equipped with highest version that is used in any of the tracks in the countries they pass.

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[16] According to the Memorandum of Understanding, signed by the industry and the European Commision (European Commission, CER , UIC , UNIFE , EIM , GSM-R Industry Group en ERFA (2008).

Box: ERTMS levels & versions

ERTMS has three different levels: level 1, 2 and 3. Level 1 and 2 are available for implementation and already in use in different countries. In the Netherlands the Betuwelijn uses ERTMS level 2 and level 1 is being used on the 'Havenspoorlijn'. Level 3 is only a concept and development of this version has stopped until level 2 functions completely as it should.

Level 1: is more or less comparable with the Dutch ATB-NG system, where lineside signals remain and balises pass information about the movement authority (maximum speeds and stopping point) to the train. The location of the train passed to the control centre is detected by a system in the track (axle counters or track circuits).

Level 2: Lineside signals are not required. Communication by GSM-R passes continuous information from the control centre directly to the cabin display. The train driver can optimize his speed as information is available for more track sections, because the driver is not limited by the visibility of the following signals . The block length of track sections can be optimized as the visibility of signals is not a limitation anymore. The location of the train passed to the control centre is detected by a system in the track (axle counters or track circuits).

Level 3: The train passes continuous information about its location and speed to the control centre. Train detection in the track is not necessary anymore. This makes it possible to use moving blocks with variable block lengths dependant on the train characteristics and speed. It is not clear when and if level 3 will be a fully functional level of ERTMS.

ERTMS versions: each level has its own versions or baselines. The levels describe the minimum level of hardware needed: level 1 can be installed as an overlay on the current ATB-system, level 2 needs GSM-R and electronic interlockings, level 3 needs a technology where the train knows its own exact location. The versions are about the way of processing the information. The most recent working version of level 2 ERTMS is baseline 2 version 2.3.0.d. As not all countries are satisfied with the functionality of this version, baseline 3 is currently being developed. This version will become available in 2015, according tot the Memorandum of Understanding signed by the European Railway Associations and the European Commission . Baseline 3 adds some functions like 'limited supervision' and 'passive shunting mode'. The differences between baseline 3 and version 2.3.0.d are mainly in the train and improve communication towards the train driver, especially in degraded modes. On the track side the differences between these versions are very small. There are no differences in capacity, safety or maximum speeds.

Compatibility between levels and versions: From version 2.3.0.d on, trains with a new version or a higher level of ERTMS can always drive on a track equipped with a lower level or version (for older versions the upward compatibility isn't guaranteed). However if the track has a higher level or version than the train, the train cannot drive on that track. This causes that a track does not have to be upgraded when a new version is implemented somewhere, but trains have to use the most recent version to be able to drive on all tracks. It is uncertain what the implications and costs are of a version or a level upgrade. Investments needed depend on the way upgrades can be installed. In the best case a software update will suffice, but it is possible that also a hardware upgrade is needed. The industry will probably be asked to make offers when installing Level 2 v2.3.0.d in rolling stock or infrastructure including the upgrade costs to baseline 3. As this is only the case since July 2008, there is no exact information yet about these upgrade costs.

See Appendix C for further information about versions and developments of ERTMS.

2.1.2 Capacity[17]

The Dutch railway network is one of the busiest networks in Europe. Every day over a million travellers are using the train[18]. No other European country has as many trains and passengers per kilometer railway track per day[19]. On a considerable number of routes capacity reaches its limits. The following corridors are expected to have capacity shortages in the near future[20]:

- The Hague – Schiphol – Amsterdam – Almere – Lelystad. Problems are especially expected between Almere and Schiphol.
- Alkmaar – Amsterdam – Utrecht – Den Bosch – Eindhoven. Capacity problems are expected between Alkmaar and Geldermalsen. For the corridor as a whole it will be difficult to create an evenly spread time schedule.
- Utrecht – Arnhem/Nijmegen. Under the assumption that cargo is routed over the "Betuwelijn", only relatively small issues are expected and small investments are needed to solve these issues.
- The Hague – Rotterdam. Large capacity problems are expected. With the introduction of the "HSL Zuid", the Dutch share of a high speed European Network, no capacity issues are expected form Rotterdam Southward.
- The Hague/Rotterdam – Utrecht. Issues with freight traffic are expected. Altering the routes for freight traffic might prevent investments in infrastructure.

Growth in passenger traffic

The number of kilometres travelled by passengers is estimated to grow from 15.7 bn kilometres in 2006 to a peak of 18 – 20 bn kilometres in 2020. After 2020 a slight decrease in kilometres travelled is expected[21]. However on certain routes an increase can still be expected after 2020, as certain area's are getting more popular for working and living.

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[17] Capacity is defined by headway (and speed). The shorter the headway, the higher the capacity. The steeper the braking curves, the shorter the headway. Source: Eichenberger (2009). *In the Crossfire of Safety, Capacity, Economics and Politics,* presentation

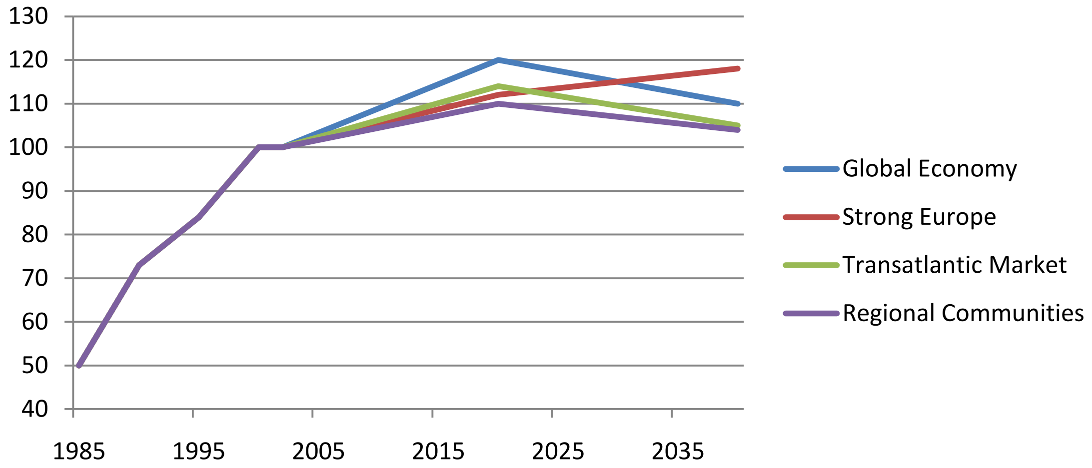
[18] Website: http://www.ns.nl

[19] CBS (2009), *Hoe druk is het nu werkelijk op het Nederlandse spoor*?

[20] Ministerie van Verkeer en Waterstaat (2007), *Landelijke Markt- en Capaciteitsanalyse Spoor*

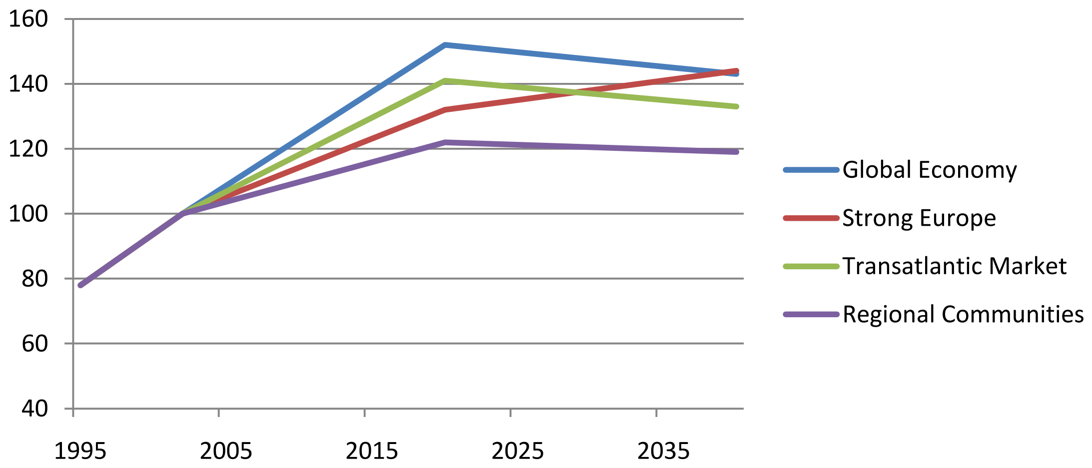
[21] Ministerie van Verkeer en Waterstaat (2007), *Landelijke Markt- en Capaciteitsanalyse Spoor*

Figure 2.1: Overall growth in train use by passengers (index 2000=100)



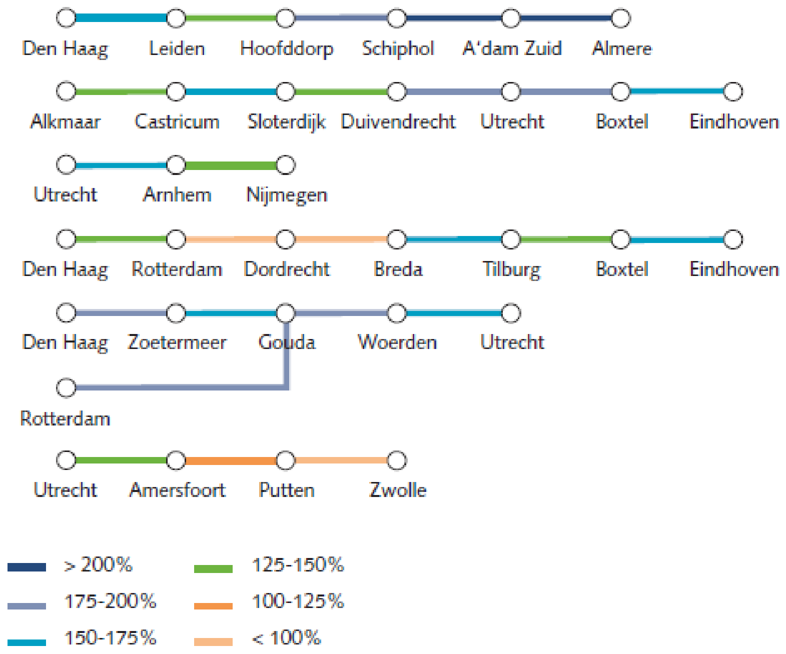
Source: KiM (2007), Marktontwikkelingen in het personenvervoer per spoor 1991 - 2020

Figure 2.2: Growth in train use by passengers, specifically for commuting (index 2000=100)



Source: KiM (2007), Marktontwikkelingen in het personenvervoer per spoor 1991 - 2020

Figure 2.3: expected growth of train intensities on selected corridors 2005-2020, average working day (Intercities and regional trains combined)



Source: KiM (2007), Marktontwikkelingen in het personenvervoer per spoor 1991 – 2020 (based on NS)

Growth in freight traffic

It is expected that rail cargo will rise to 46 – 85 mio tons transported in 2020 compared to 41 in 2006[22]. However the minister of transport notified that a development towards the upper boundary is more likely[23]. The expectations for 2040 have an even greater bandwidth as is shown in figure 2.4.

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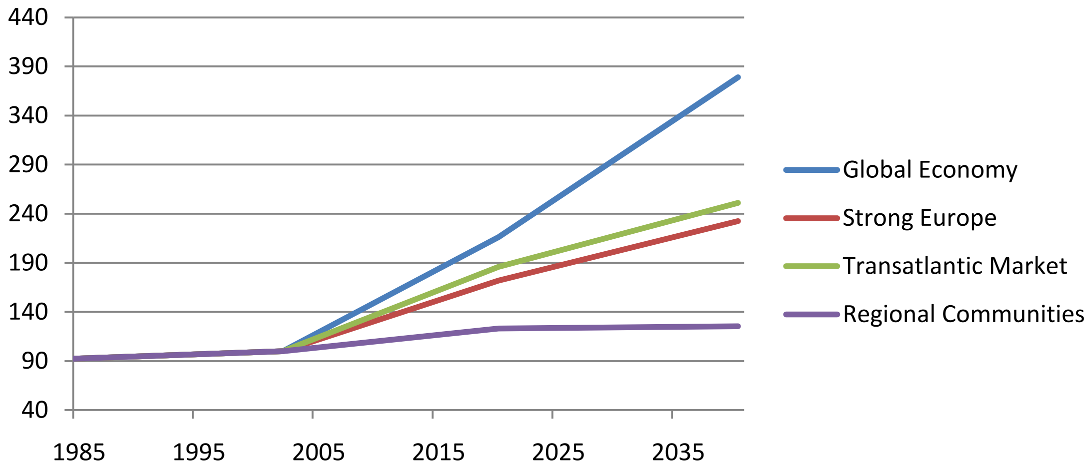
22 Ministerie van Verkeer en Waterstaat (2007), *Landelijke Markt- en Capaciteitsanalyse Spoor*

23 ProRail, NS, BRG (2008), *Programma Hoogfrequent Spoorvervoer, Verkenning benodigd investeringsvolume*

*Figure 2.4: Expected growth of rail cargo in freight traffic by rail (in tonnes*kilometres, index 2002=100)*



The possible impact of ERTMS on capacity is uncertain. In most cases where ERTMS is in use a gain in capacity is reported, but in most cases the implementation of ERTMS was combined with other measures[24]. The analysis of capacity effects of ERTMS is further complicated by the possible interaction with existing programmes for increasing physical capacity on the Dutch railway network (see also section 2.2.2 on the PHS programme)

2.1.3 High speed

Currently trains in the Netherlands are able to drive up to 140 km/h. Technically rolling stock could reach speeds up to 160 km/h, but the current ATB signalling system limits speeds to 140 km/h. At the moment of writing there are discussions if adjustments to the ATB system could be made to enable trains running 160 km/h. With some adjustments to the current signalling system, speeds up to 160 km/h should be possible on the routes mentioned below[25]. Still, parties involved have not yet reached an agreement. In addition, European legislation, the TSI (technical specification for interoperability), might prevent these investments in adjustments to the current system. ERTMS would allow speeds of 160 km/h for certain on the following sections:

- The “Hanzelijn” (Lelystad – Zwolle)
- Leiden – The Hague
- Amsterdam – Utrecht
- Boxtel - Eindhoven
- Almere – Lelystad

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24 See for example SBB (2001*), Kapazitätssteigerung, Schlussbericht Phase 1.*

25 Bureau Onderzoek en Rijksuitgaven (2008). *BOR NOTITIE Reistijdverbetering spoor*.

ERTMS L2 with cabin signalling can cope with speeds up to 500 km/h. On conventional lines in the Netherlands speeds above 160 km/h would only be possible with additional investments in infrastructure and power supply. On other then the mentioned routes, the infrastructure is not capable of speeds above 140 km/h, due to sharp curves, level crossings, switches designed for lower speeds, weak foundations, stations etc. In some cases minor adjustments in legislation can be sufficient to increase the maximum speed (e.g: speeds over 140 km/h are not allowed on tracks with level crossings). In other cases major adjustments in the infrastructure are needed.

Another advantage of ERTMS is the fact that discrete speed steps disappear. With ATB speeds are limited to 40, 60, 80, 130 or 140 km/h. When speeds of 50 km/h are possible on a piece of track, it is now limited to 40 km/h. In this example, a gain of 25 percent in speed is possible on this track section. Another advantage of ERTMS is the fact that ATB tells the train to start or not to start braking when it passes a signal. It is calculated for the worst braking train and the maximum allowed speed on track. If a train is light or drives slower than the maximum speed allowed, the train will brake earlier than necessary. ERTMS tells the train on which point the train has to come to a stop when it passes a (virtual) signal. Specific characteristics of the train and the actual speed of the train can be included in the braking instruction, and the train does not have to brake directly.

Box: Braking curves
In its implementation strategy of 2006 the infrastructure manager ProRail and operator NS assumed one to several minutes of travel time reduction per trip (based on 10-30 seconds every stop), due to the optimization of breaking curves and reducing headway. The uncertainty of these effects is illustrated by a later assessment of the same effect by ProRail and NS indicating that travel time reductions of several seconds for every stop are probably the highest achievable. Source: ProRail / V&W/DGM0-2009/7375

2.1.4 Safety

One of the limitations of the ATB system is that it does not intervene at speeds under 40 km/h. This resulted in over 1200 signals passed at danger (SPADs) in the period 2003 – 2007. In 31 percent of the cases the SPAD did not have any consequences, in 52 percent it resulted in a delay only. In over 13 percent the infrastructure was damaged (mainly switches), in 1.4 percent a collision of trains was the result (0.1 percentage point with lethal damage and 0.4 percentage point with physical injuries), in 0.2 percent the train got derailed without lethal or physical damage and in 2.7 percent a dangerous situation arose (without any damage) as the train passed an open level crossing.[26] ERTMS can influence trains driving under 40 km/h. This should reduce the number of SPADS dramatically compared to the current situation. However an already running programme to implement ATBVV (which does intervene at speeds under 40 km/h) on the 1100 most dangerous locations (already completed) and an additional 100 spots, should reduce the number of SPADS by 50 percent and the risks of SPADS by 75 percent[27].

[26] Inspectie Verkeer en Waterstaat (2008), *STS-passages 2007.*
[27] ProRail (2008), *Beheerplan 2008.*

Another benefit of ERTMS is the possibility of temporary speed limits needed for tracks in bad condition and running-in newly constructed tracks. Nowadays signs indicate these temporary speed limits, with ERTMS they can be enforced as it should be easy to adjust speed limits temporarily with an ICT based system. It is also possible for track workers to close a part of the track where they are working with a handheld terminal, which improves their safety.

2.2 Current investment programmes and the “null alternative”

To assess the impacts of ERTMS implementation strategies, it is necessary to know what will happen if no specific implementation strategy is followed. This situation is called the “null” alternative. Not carrying out a (infrastructure) project usually does not mean everything remains as it is today. Therefore SCBA guidelines prescribe that all other policy measures are taken into account in a situation where no project alternative is carried out. In our analysis we therefore assume that all current and planned ATB improvement and infrastructure programmes will be carried out and also that some ERTMS projects will take place.

Before the null alternative is presented in more detail, it is important to have a good understanding of two major Railway programmes that are planned in the Netherlands and that could interact with the implementation of ERTMS. These programmes are the signalling systems replacement programme “Mistral” and the programme that is aimed at creating capacity to enable very high frequency passenger services on main lines, the “Programma Hoogfrequent Spoor” or “PHS”.

2.2.1 Signalling systems replacement programme “Mistral”

The Mistral programme is being developed as a replacement programme of signalling systems that have reached the end of their economic or technical lifecycle. Mistral consists of three parts called plateau 1, 2 and 3 and will be carried out in the period 2010-2018. Plateau 1 is worked out in some detail, the way plateau 2 and 3 will be carried out is less certain. On average over the whole period signalling systems will be replaced on 55 routekm yearly. The first plateau will be carried out at some 20 km per year, plateau 2 & 3 will average approximately 70 routekm yearly.

The first generation ATB signalling system originates from the fifties. On several locations equipment (interlockings and other elements) of the ATB system is at the end of its lifecycle. The replacement programme is called Mistral, and will be executed in the period 2010-2018. However, the technical specifications for the Mistral programme are not worked out in detail for the entire period. One of the main unanswered questions is which equipment should replace the current system. Is renewal of the ATB equipment sufficient, e.g. using B-relay technology for the interlockings, or should the new equipment be able to adapt to ERTMS, e.g. be based on electronic interlockings?[28]

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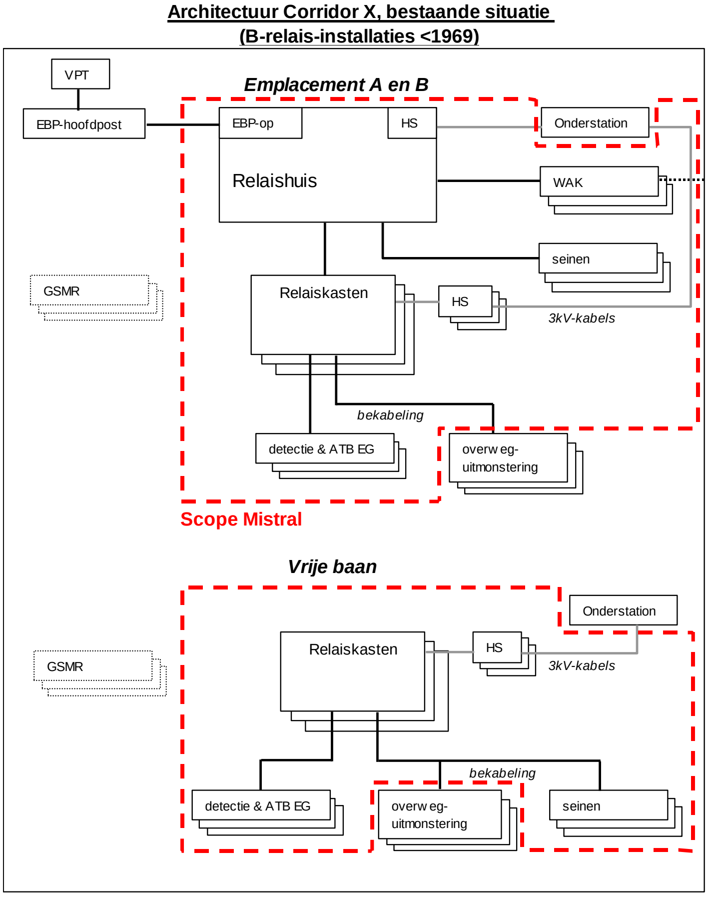
[28] See also sections 2.2.3 and 3.2.1.

The scope of the programme

The Mistral programme involves the replacement of existing B-relay equipment from the period 1953-1968 including the exterior elements, on 475 kilometres of railway tracks (route kilometres, plateau 1, 2 and 3). Interlockings, signals, train detection, train protection, wires are parts that need to be replaced[29]. Under the Mistral programme a total number of 70 interlockings will be replaced by 2018. According to ProRail this adds up to just under 20% of the entire signalling system[30]. The technical scope of the replacement programme is shown in the schematic illustration below.

Figure 2.5: Technical scope of the Mistral replacement programme: parts within the red dashed line are subject to replacement



Source: ProRail (2009), *Financiële Analyse, Bijlage 1 bij Business Case Mistral integrale Vervanging & ERTMS*

According to ProRail the new signalling system has to meet the requirements that train traffic and system maintenance put forward today and tomorrow. This means that it should improve RAMS per-

[29] ProRail (2008). *Met Mistral op weg naar ERTMS*, Presentation

[30] ProRail (2008). *Beheerplan 2009.*

formance (Reliability, Availability, Maintainability and Safety), reduce lifecycle costs, add new functionalities (like ERTMS), and improve labour conditions for railway track workmen[31].

Mistral approach

The mistral programme includes 23 railway corridors on which the equipment will be replaced. The programme's approach is divided in three phases called "plateaus". Plateau 1 involves three corridors and is planned to achieve completion by 2013. Plateau 2 and 3 involve the other twenty corridors and will be executed in the period 2013-2018. See the table below. The division of the corridors nor the exact timing in the plateaus 2 and 3 are determined yet.

B-relay equipment replacement measures after completion of the Mistral programme in 2018, are not specified. It is assumed that 2,5 percent of the signalling installations in the network will be replaced yearly (which represents 50km yearly of the scope of this study).

Table 2.1: Mistral corridors, Plateau 1, Plateau 2 and 3

Plateau 1 (till 2013)	Route km
Sittard - Maastricht	22
Den Dolder - Baarn - Amersfoort	19
Deventer - Apeldoorn	14
Plateau 2 and 3 Mistral 2013 – 2018	
Amersfoort- Apeldoorn	44
Beverwijk – Santpoort Noord	6
Deventer – Almelo	39
Almelo – Hengelo – Enschede	23
Sittard – Heerlen	14
Roermond – Sittard	24
Geldrop – Roermond	47
Geldermalsen (Meteren Betuweroute aansluiting) – Den Bosch – Tilburg	48
Utrecht (Lunetten) – Geldermalsen (Meteren Betuweroute aansluiting)	26
–Utrecht (Blauwkapel) - Amersfoort	21
Gilze-Rijen – Tilburg - Boxtel	28
Zevenbergen – Roosendaal grens	24
Uitgeest – Zaandam	13
Hilversum – Utrecht (Blauwkapel – Lunetten)	18
Moordrecht overloopwissel – Nieuwkerk aan de IJssel	4
Nijmegen - Blerick	61
Emplacementen Hoek van Holland, Maassluis, Vlaardingen centrum	0
Emplacement Zevenaar	0
Emplacement Delft	0
Emplacement Naarden - Bussum	0

Source: ProRail update given by e-mail, September 3, 2009.

31 ProRail (2008). *Met Mistral op weg naar ERTMS*, Presentation

Plateau 1 has two main objectives. Apart from the replacement of the equipment on the above mentioned corridors, it is also meant to create a Level Playing Field for suppliers of signalling system. To ensure continuity and competition among suppliers, it is in ProRail's interest to be able to choose from several suppliers of signalling systems. Three suppliers have been chosen to carry out Plateau 1. Each of these suppliers will probably be assigned one of the three corridors of Plateau 1.

The replacement will be carried out on a corridor by corridor approach. This means that after replacement, all present systems on the corridor that contain signalling intelligence will have been replaced by systems of one type. This way it is achieved that operators and maintenance deal with one system and complex interfaces are avoided. In the end this approach leads to cost savings.

The order in which the corridors are subject to the replacement of their systems is determined by the age of the system. This means that the systems on the oldest junctions and tracks will be replaced first. However, this rule is not taken too strictly if there are good reasons to opt for another phasing.

Several large projects in the field of train protection are being carried out simultaneously, and they will likely interfere in each other's planning. Other projects are for instance implementation of the level crossing failure monitoring system DOSS and the extension of the ATB system in order to avoid signals passed at danger (SPADs), ATBVV. Besides those there are the regular projects and projects from other departments of ProRail on the same infrastructure Mistral focuses on. There is a large chance that these projects will influence each other. Synchronisation between the different projects will have its impact on the planning.

Systems for replacement

The question of which technical system and components ProRail chooses to replace the old equipment with, depends mainly on the aging pace of existing equipment and on strategic decisions that are yet to be made.

The aging pace of existing equipment has forced the replacement to start in 2008. For future functionality based on new technologies, ProRail states that strategic decisions need still to be made. These decisions involve functionality issues, like ERTMS, and suppliers' policies. Only after these strategic decisions have been made, (additional) system developments can be started up. To deal with this situation ProRail department "Train Protection" chooses to compose or, if necessary, to develop a limited number of technical solutions for the Mistral corridors that can deal with a variety of different functions[32].

New combinations of systems will result in new technological solutions, which then can be applied to certain types of corridors. It is possible that for a corridor on the main network a different solution is applicable than for a corridor on one of the secondary lines. For the first corridors in the replacement

[32] ProRail (2005), *Work hypothesis Mistral 2005.*

programme (plateau 1) a solution is chosen that will be built up around electronic interlockings of probably three different suppliers to create a level playing field.

The new electronic interlockings are containing a high number of interfaces with other systems (for example different type of signals and detection methods). As each corridor has its own characteristics, it is possible that an interlocking is released for one corridor, needs to be adjusted for another corridor. The use of new technology causes therefore that development of the system will continue for the forthcoming years, until all functions and interfaces needed are included.

The release of electronic interlockings initially focused on the application of the system to railway junctions. In some cases the system is also applicable for securing the open track (comparable to e.g. the application of EBS around Rotterdam). However, this is not the case in all situations, including infrastructure that lies within the scope of Mistral. This is mainly a result of differences in processes, procedures and operation methods between junction signals and regular track signals. The result of this is that the already approved safety cases of electronic interlockings are not right away applicable on the (operated) open track.

In order to reduce the number of interfaces and by doing so reduce life cycle costs, the signalling system will no longer be projected from large railway stations with a classic open track signalling system in between. The signalling system is projected for the whole corridor and operated from one central computer. This way the open track can also be operated when desired.

The initial ambition of ProRail was to integrate ERTMS functionality into future Mistral solutions. However, the Minister has decided to wait for the release of ERTMS level 2 baseline 3, that is expected to become available in 2015.

ProRail sees replacing all old equipment with ERTMS as the ideal approach for national ERTMS implementation[33]. But the implementation strategy for ERTMS has not been determined and there is a shortage of trains that can run on ERTMS. ProRail has decided to already start the replacement of the old signalling equipment. For bridging the gap until a national implementation strategy is chosen, ProRail decided to implement ATB and at the same time prepare the system components for ERTMS implementation for the first plateau of Mistral[34]. This strategy is however reviewed, as there is a lot of uncertainty about future ERTMS implementation and the possibility of actually preparing ATB installations for efficient future ERTMS upgrades.

2.2.2 High frequency services programme "PHS"

The "Programma Hoogfrequent Spoorvervoer" (PHS, programme for high frequency rail traffic) plans to solve the most important foreseeable capacity issues. Corridors studied are Utrecht – Arnhem,

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33 ProRail (2008). *Met Mistral op weg naar ERTMS*, Presentation

34 ProRail (2008). *Met Mistral op weg naar ERTMS*, Presentation

Utrecht – Den Bosch, The Hague – Rotterdam and Schiphol – Amsterdam - Almere – Lelystad (options for the short and long term). The PHS objective is to run 6 intercity trains each hour on these corridors in combination with several regional and freight trains. Another subject of the PHS study is to create "future proof" routes for freight traffic by rail. PHS is planning to solve all problems on routes where lack of capacity will become an issue. ERTMS plays no direct role in PHS and the question is if ERTMS could have an additional value to this programme. Also PHS will adjust signalling systems on some locations, creating possibilities for costs efficiencies for nation wide ERTMS implementation.

Why PHS

The ambitions of the Minister and the sector for the development of rail transportation are not possible within the capacity (infrastructure and environment) as foreseen for 2020 in the MIRT 2008 and the "Herstelplan Spoor" programmes.[35]

The Minister's ambition for growth and quality of passenger and freight transportation by rail for 2020 comprehends:

1. High frequency rail traffic on the busiest routes in the greater Randstad area. This means a frequency of at least six intercity trains per hour and a customized integration of the regional trains, in a recognisable service that is as steady as possible.
2. Coherent regional public transport systems, with rail transportation as their backbone. The regional trains are the backbone of the regional public transport system. The most important components are the connections of the regional lines with the main railway network and the connections with bus/tram/underground.
3. Quality of travel times to the peripheral parts of the country. The increase of the train traffic (passengers and freight) will go together with offering better quality of travel times to the peripheral parts of the country.
4. Future proof routes for freight traffic by rail. The growth of freight rail traffic will mainly be accommodated on the Betuweroute. On the mixed network the total volume in 2020 will be back on the present level after an earlier decrease, but on other routes. For accommodating these freight flows a route strategy is needed. This route strategy is also of importance for the ambition for high frequency passenger traffic, since freight traffic often causes large capacity problems. Therefore it is important to route the freight traffic as much as possible away from the busy passenger tracks.

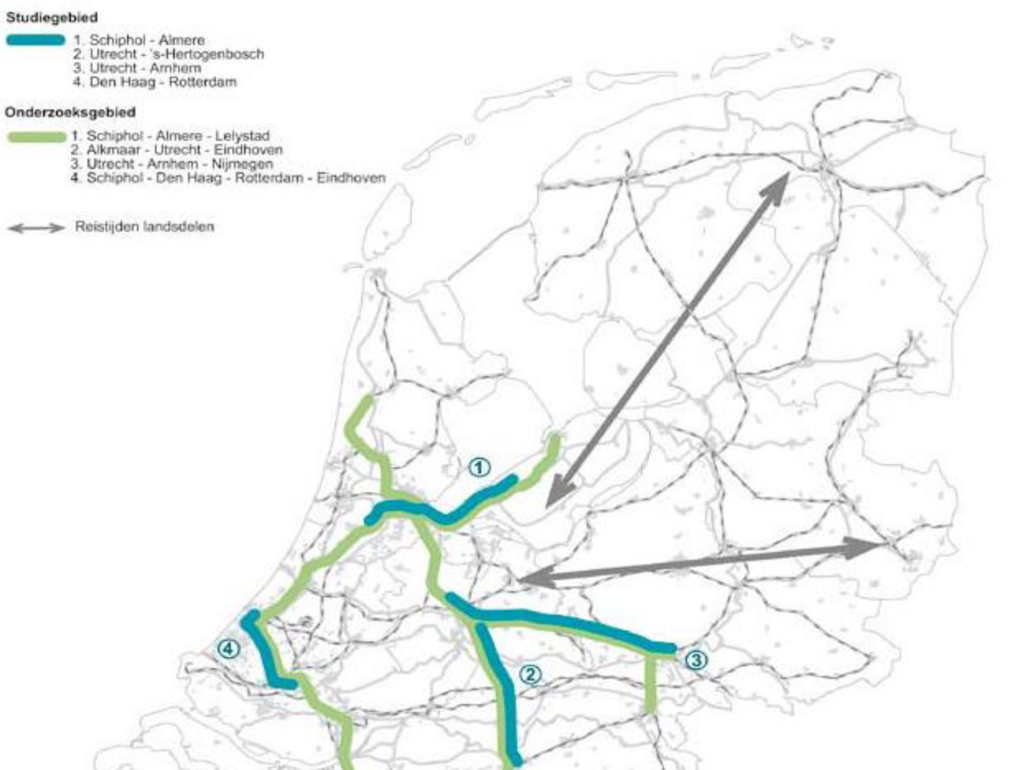
Bullet 1 and 4 are the main goals to be reached by executing the PHS programme. Based on the outcomes of the Netwerkanalyse Spoor (NS/ProRail/BRG, 2007) and the Landelijke Markt- en Capaciteitsanalyse Spoor (LMCA, V&W, 2007) the Minister has come to the conclusion that market expectations of passenger kilometer totals for 2020 and growth expectations of freight traffic, need

[35] ProRail (2008). *Programma Hoogfrequent Spoorvervoer, Verkenning benodigd investeringsvolume*

to be raised[36]. High frequency rail traffic can be implemented gradually in relation to the expected increase in passenger numbers. On some routes forecasts predict that not only the frequency of the train services needs to be increased, but also improvement of infrastructural capacity is needed. This is the case on the next routes in the PHS programme:

1. Schiphol – Almere – Lelystad (OV-SAAL)
2. Utrecht - Arnhem
3. Utrecht - Den Bosch
4. Den Haag – Rotterdam

Figure 2.6: PHS corridors



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36 ProRail (2008). *Programma Hoogfrequent Spoorvervoer, Verkenning benodigd investeringsvolume*

The scope of PHS

The main objective of the High Frequency Railway Transport Programme is to solve the main capacity shortages on these routes. In the national budget of 2009 a reservation of € 4,5 billion has been made for PHS[37]. This budget includes OV SAAL that has already been started up. Besides direct infrastructure extensions, PHS includes also measures to reduce hindrance of, noise, safety and closed level crossings caused by the expansion of the train service.

Table 2.2: Total budget High Frequency Railway Transport Programme

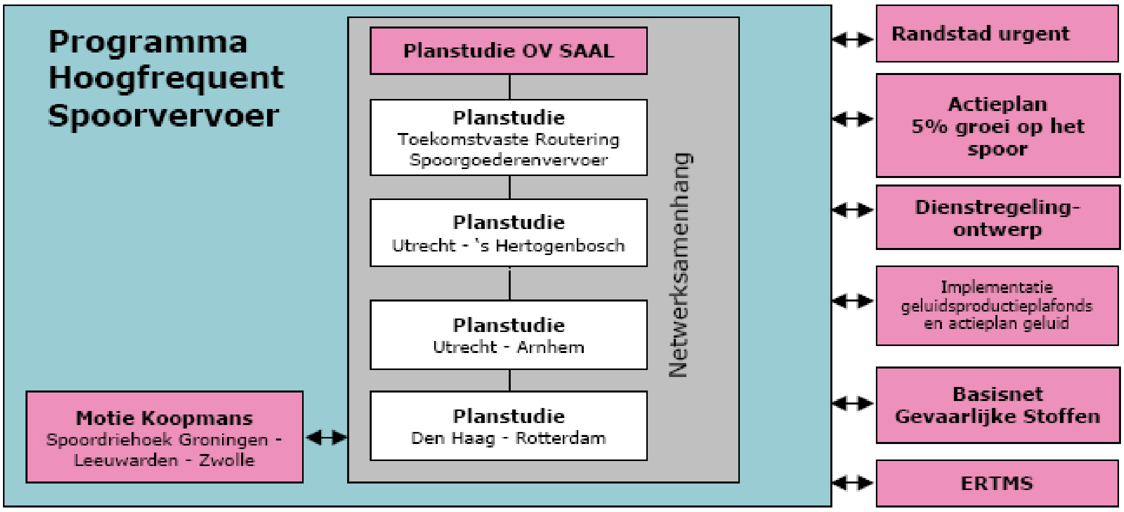
Programme component	Budget
Study OV SAAL short term	€ 606 million
1st fase Study OV SAAL 2020	€ 744 million
Studies:	
* Future proof routes for freight traffic	
* Utrecht – Arnhem	€ 2,929 million
* Utrecht – Den Bosch	
* Den Haag – Rotterdam	
Motion Koopmans (Northern Netherlands)	€ 160 million
Spoorzone Delft	€ 61 million
Total (incl VAT)	**€ 4,500 million**

The four studies 'Den Haag – Rotterdam', 'Utrecht – Den Bosch', 'Utrecht – Arnhem' and 'Future Proof Routes for Freight Traffic' are components of PHS. The study OV-SAAL (Schiphol Amsterdam Almere Lelystad) is also a component of PHS, but it follows a different study and decision making procedure. The study Den Haag-Rotterdam is also part of the Randstad Urgent programme. The investment programme for the northern Netherlands (Het pakket voor het Noorden, incented by the parliamentary motion of Koopmans) is also undergoing its own study and decision making procedure.

The illustration below shows the scope of PHS and the projects that have an important connection to the programme.

37 Ministerie van Verkeer en Waterstaat (2009). *Programma Hoogfrequent Spoorvervoer, Tussenrapportage vervoer- en capaciteitsanalyse*.

Figure 2.7: Functional scope of the PHS programme and related projects



Source: V&W, *Programma Hoogfrequent Spoorvervoer, Plan van Aanpak tot projectbesluiten in juni 2010*, 16 februari 2009

Possible capacity effects of ERTMS before 2020 need to be determined, so adequate measures for PHS can be planned.

Variants

For the three corridor studies two variants have been developed. In Variant 1 six intercity trains operate on the busiest tracks in the greater Randstad area, whereas the number of regional trains depends on market demands. In Variant 2a there are six intercity and six regional trains operating per hour on the busiest tracks in the greater Randstad area. Variant 2b differs from Variant 2a in the sense that there is a lower frequency of regional trains on the Zaan line, the corridor Utrecht-Arnhem and Geldermalsen-Tiel-Den Bosch route.[38]

Based on intermediate results it has become clear that Variant 2 does not fit within the available budget if the principles remain unchanged.[39]

For the study Future Proof Routes for Freight Traffic two variants have been developed: spreading and bundling. The new routes are meant to increase the use of the Betuwe Route, create good supplying connections for freight traffic via the mixed network and create space for passenger traffic on parts of the mixed network.

38 NS (2009). *Tussenrapportage vervoersanalyse reizigers 2020 Pogramma Hoogfrequent Spoor*.

39 Ministerie van Verkeer en Waterstaat (2009). *Programma Hoogfrequent Spoorvervoer, Tussenrapportage vervoer- en capaciteitsanalyse*.

In the ‘Spreading’ variant the most important freight flows to the frontier crossings are routed via several main routes: Betuwe Route, Amsterdam, Utrecht, Arnhem, Breda and Den Bosch. In ‘Bundling’ freight flows are routes as much as possible via the Betuwe Route and a fewer number of other routes: Utrecht, Arnhem and Den Bosch.[40]

Based on intermediate results, it has turned out that several freight routing options are possible in Variant 1, amongst those there are several options for spreading. In Variant 2 there is a limited number of possible routing options which all involve more bundling on the Betuwe Route. [41]

According to V&W the routing question of freight traffic can be reduced to three main considerations[42]:

1. Freight traffic to and from the Amsterdam port area: via Amsterdam Amstel or via Diemen and Watergraafsmeer.
2. Freight traffic from Kijfhoek to the south east: via Breda (the Brabant route), Den Bosch or a combination (roundabout) of both routes.
3. Freight traffic from Kijfhoek to the northern and eastern Netherlands: via Rotterdam (Willemsspoor Tunnel) – Gouda – Amsterdam, via Betuwe Route–Utrecht-Amersfoort, via Elst-Arnhem-Deventer or a combination (roundabout) of these routes.

Necessary investments

From the results of the capacity analysis carried out in the scope of the PHS programme[43], it has become clear what measures are needed on the corridors (and the connecting tracks) in the different variants to realize PHS.

Corridor Utrecht-Den Bosch:

- The bigger part of the investments on this corridor is needed for measures between Utrecht and Den Bosch. Apart from that several measures are needed on the stretch Den Bosch-Vught and in Liempde and Uitgeest.
- The bigger part of the investments in both Variant 1 and 2 are accounted for adjusting Utrecht Central Station to be able to deal with a higher constant flow of trains and the quadruple track on the Culemborg-Meteren line between the bridges over the rivers Lek and Waal. Apart from that there are projects for signal optimalisation on the stretch Amsterdam Centraal-Amstel-Bijlmer, a railway junction Amsterdam Centraal, measures at Liempde (in Variant

[40] Ministerie van Verkeer en Waterstaat (2009). *Programma Hoogfrequent Spoorvervoer, Tussenrapportage vervoer- en capaciteitsanalyse*.

[41] Ministerie van Verkeer en Waterstaat (2009). *Programma Hoogfrequent Spoorvervoer, Tussenrapportage vervoer- en capaciteitsanalyse*.

[42] Ministerie van Verkeer en Waterstaat (2009). *Programma Hoogfrequent Spoorvervoer, Tussenrapportage vervoer- en capaciteitsanalyse*.

[43] Ministerie van Verkeer en Waterstaat (2009). *Programma Hoogfrequent Spoorvervoer, Tussenrapportage vervoer- en capaciteitsanalyse*.

1: reducing headway, in Variant 2: flying junction), reducing headway, and dynamic traffic management and additional changes at Geldermalsen.

- Apart from the above mentioned measures, dependent on the freight traffic routing, additional measures are needed, like measures for the railway junction Utrecht, a flyover at Utrecht south side and the north-western bend at Meteren.
- In case of extra regional trains, triple or quadruple tracks (dependent on the freight traffic routing) will be needed between Hedel and Zaltbommel.
- In case of Variant 2a (more regional trains) the platform capacity of Uitgeest on the Zaan line needs to be increased.

Corridor Utrecht-Arnhem

- The higher frequency in Variant 1 is possible within the budget of already planned investments in the Long Term Programme for Infrastructure, Spatial Development and Transport (MIRT). For this Variant no extra investments are needed on the corridor Utrecht-Arnhem.
- Between Nijmegen and Arnhem, dependent on the freight traffic routing, there is a need for a flyover at Elst and a third/fourth track between Elst and the Betuwe Route.
- In case of Variant 2, a shunting track is needed in Driebergen and an additional side platform in Ede.
- On the line Utrecht-Arnhem in both Variant 1 and 2 few minutes of travel time are gained; in Variant 2 the gain in travel time is somewhat bigger.

Corridor Den Haag-Rotterdam

- The supposed train numbers in Variant 1 can be accommodated with help of the planned MIRT investments. Dependent on the freight traffic routing, two other projects are needed: increase of signal density and reducing headway.
- The higher frequency in Variant 2 requires additional investments: triple tracks between Den Haag Centraal and Den Haag Hollands Spoor, quadruple tracks between Rijswijk and Schiedam with necessary modifications at Rotterdam, and a flyover at Rotterdam for the HST.

Future proof routes for freight traffic

The results of the study of the future proof freight routes show which routes are most suitable in the different variants. [44]

- In regard to the freight route from Utrecht/Rotterdam to the Amsterdam port area, there is a clear preference for a route via Amsterdam Amstel.
- In Variant 1 the question is how to divide the freight traffic over six freight routes via Rotterdam, Utrecht and Arnhem.

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[44] Ministerie van Verkeer en Waterstaat (2009). *Programma Hoogfrequent Spoorvervoer, Tussenrapportage vervoer- en capaciteitsanalyse*.

- In Variant 2 only customized freight train frequencies are possible through the Willemsspoortunnel Rotterdam. This problem can only be solved with costly and complex adaptations to the tunnel infrastructure in Rotterdam or rigorous modifications in the passenger service schedules. Besides, the OV-SAAL study shows that a combination of a 6/6 passenger service in combination with freight trains would lead to investments stressing beyond budget limitations. It shows also that for the long term of OV-SAAL a combination of passenger and freight trains in some of the alternatives leads to additional investments. The bottleneck at the Willemsspoortunnel and the high costs for routing through the SAAL corridor resulted in the dropping of the freight route Rotterdam-Gouda-Amsterdam via the OV-SAAL corridor to the northern Netherlands during the study.
- With regard to the routes via Arnhem the route via a bend at Deventer is much less costly than the route via the Twente Canal Line (Zutphen-Hengelo). As a result, this line was dropped during the study.

ERTMS interaction with PHS

In this study three possible interactions are taken into account:

1. directly, where PHS includes updating/new signalling installations
2. indirectly, where cost reductions can be obtained by installing ERTMS equipment simultaneously with other infrastructural measures
3. also indirectly, when ERTMS allows for optimization of operations, hence reducing bottlenecks, and making physical PHS projects superfluous.

For all three interactions it is imperative that investments can be synchronized.

2.2.3 The Null and Null+ alternative

In this section the situation where no actual implementation strategy is followed is described in more detail. In addition to this null alternative also a null+ alternative is used in this study. This null+ alternative was introduced to take into account that choices made in MISTRAL programme and future developments (e.g. the possibility to combine ERTMS with B-relay technology) might be of substantial impact on the costs of ERTMS implementation. In the null alternative it is assumed that the Mistral programme will be carried out using relatively cheap b-relay technology. However, it is also possible to use the more expensive electronic interlockings in the Mistral programme, reducing the additional costs for ERTMS in the implementation strategies significantly[45].

The null and null+ alternatives are considered to be the same in both timing and phasing of investments in infratsrcuture and rolling stock, but the technology used for renewing interlockings under the Mistral programme differ.

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[45] See also section 3.2.1.

Infrastructural measures in the null(+) alternative

The main characteristics of the null alternative are:

- Execution of "Mistral" (replacement programme of current end of life signalling systems, including outside elements) without the implementation of ERTMS. Short term (2010-2013) measures are described as "plateau 1". The second part until 2018 is less strictly defined; after 2018 measures cannot exactly be described by ProRail. As the exact content of the Mistral programme is unknown for the long term we assume in our calculations that each year 2,5% of signalling systems in the network will be replaced. This assumption is based on the economical lifecycle of the ATB system of 40 years.
- In the null alternative all measures that are already planned in the long term Programme for Infrastructure, Spatial policy and Transport (MIRT) and the Programme High Frequency Rail transport "PHS" will take place. Other than that, no further network expansions are foreseen.
- ERTMS will be implemented on routes if it is mandatory or otherwise (internationally) agreed upon. ERTMS levels are not specified, so Level 1 and Level 2 are possibilities both as "only" or as dual signalling/overlay. The two parts where ERTMS is absent (known as "the isles") on the 'Betuweroute' (part of Corridor A: Rotterdam – Genoa), will be completed in 2015. The Port of Amsterdam will be accessible for ERTMS trains in 2020[46].
- The implementation of ATB VV (improved version) will be executed as planned.
- Only international trains on international corridors will have advantages of ERTMS. National passenger trains will not be fitted with ERTMS, and will have no advantages. New freight trains entering service will be equipped with ERTMS.

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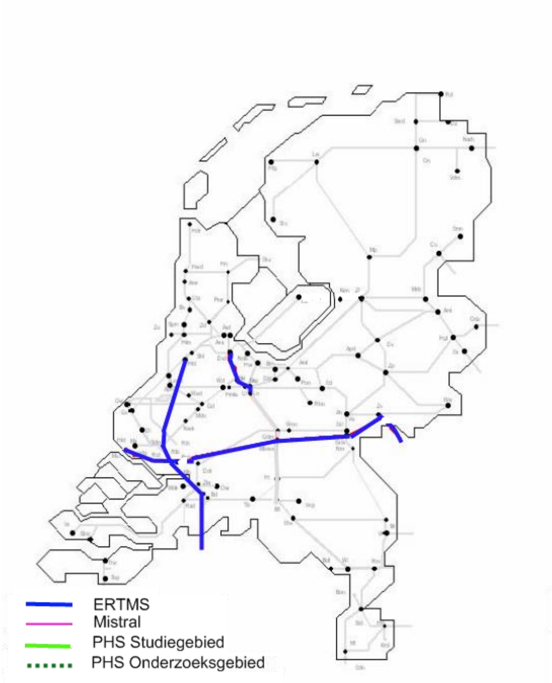
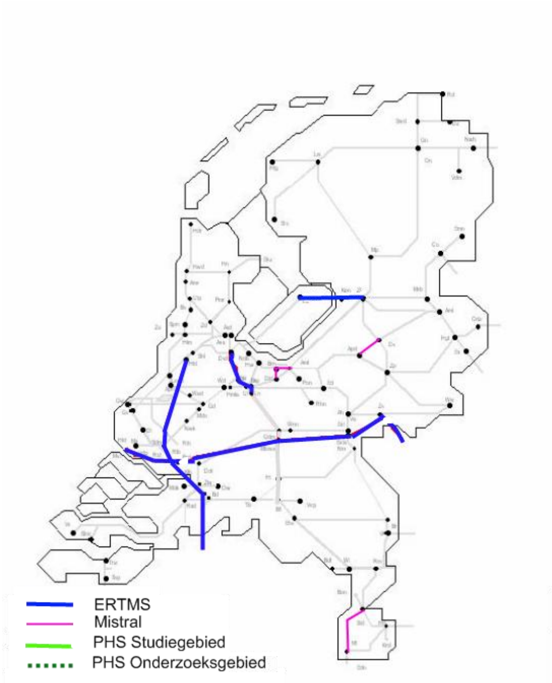
[46] According to the European Commission Decision of 22.7.2009 amending Decision 2006/679/EC, the ports of Amsterdam and Antwerp shall be connected to the Rotterdam Genoa corridor no later than 2020. According to the ProRail-ERTMS-coordination meeting of September 16, 2009, these track sections will be laid out as dual signalling.

Null alternative 2010

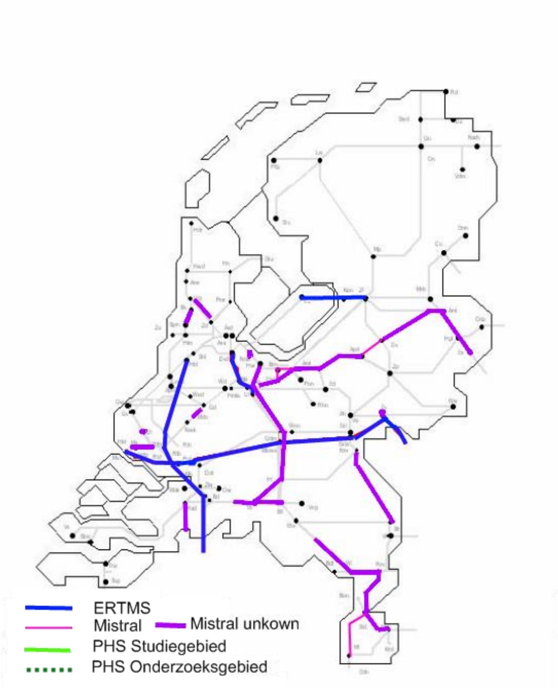


Null alternative 2013

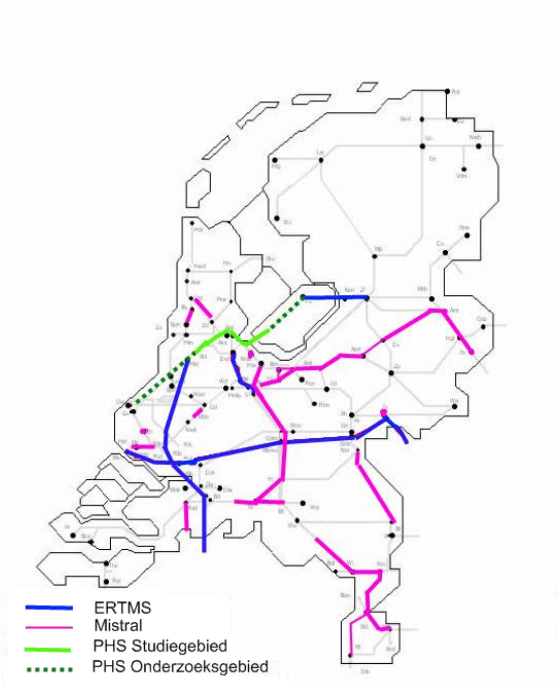


The first part of replacement programme Mistral (“plateau 1”) will be completed in 2013. The second part of the Mistral programme will be completed in 2018. ProRail has not yet worked out a detailed programme for this part, so it is still uncertain in what order the Mistral projects will be carried out. We therefore assume that the investments of the second and third part of Mistral plateau are evenly distributed over the years 2013-2018. This is the reason the 2013 map shows no specific additional Mistral investments. The 2013 map does show the Hanzelijn, as it is planned to come into service in this year.

Null Alternative 2015



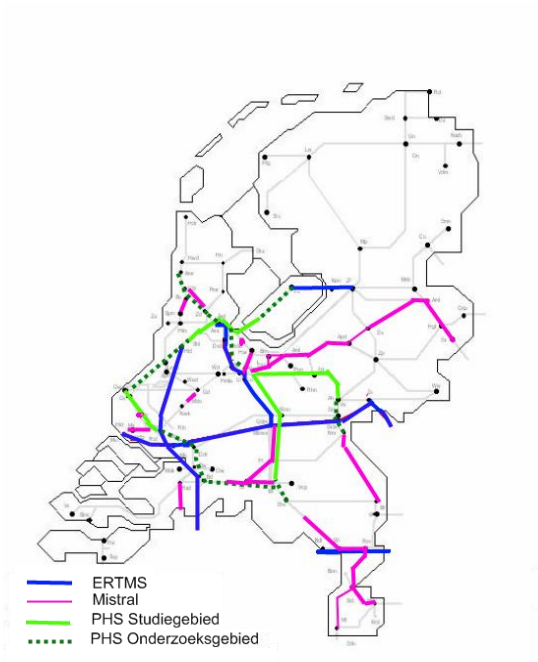
Null Alternative 2018



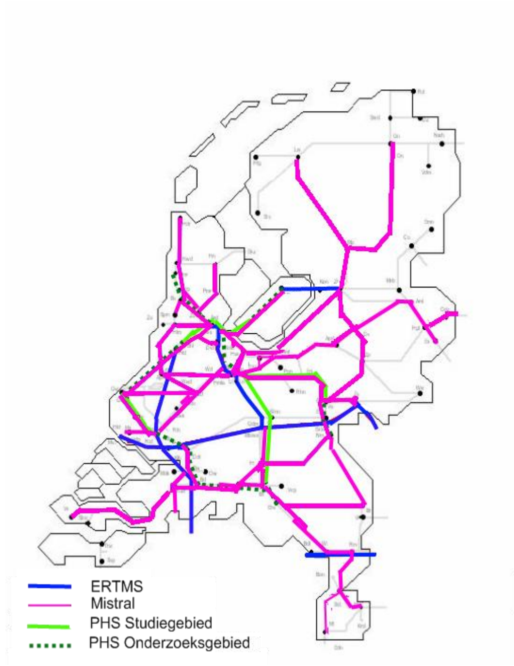
New ERTMS equipment in the infrastructure for 2015 is foreseen in the “isles” in the Betuweroute by international agreement. In 2018 the second part of the Mistral programme, 20 corridors[47], will have been completed. The 2018 map also shows the first measures of PHS (the OV-SAAL corridors starting 2016).

47 These corridors are listed in section 2.2.1.

Null Alternative 2020



Null Alternative 2045



In 2020 OV-SAAL investments will have been completed. All projects that make up the PHS programme will be completed the same year. In addition the connection of the port of Amsterdam to the Betuweroute will be fitted with ERTMS. The Iron Rhine is also indicated on the map, because connecting Antwerp (and Amsterdam) to the European ERTMS TEN-network is compulsory by the year 2020.

Mistral measures after 2018 are not specified. It is assumed that 2,5 percent of the signalling installations in the network will be replaced yearly.

Table 2.3: Summarizing table of ERTMS infrastructure in the null alternative

Routelength (in km)	2010	2013	2015	2018	2020	2028	2045
Total length ERTMS routes (cumulative)	290	340	340	340	430	430	430
New per period	290	50	0	0	90	0	0
Of which							
ERTMS replacements (Mistral) per period							
Other ERTMS investments per period	290	50			90		
Total ATB replacements (Mistral) (cumulative)		55	200	430	520	850	1570

2010: total length of ERTMS corridors adds up to 290 km. This is due to de Betuweroute (excluding islands) the HSL Zuid and Amsterdam-Utrecht.

2013: the Hanzelijn is completed, adding 50 km to the ERTMS network, totalling 340 km. Also the first part of Mistral will be finished, renewing ATB signalling systems on 55 km of routes (Sittard Maastricht, Den Dolder-Baarn-Amersfoort, Deventer Apeldoorn).

2015: the "isles" in the Betuweroute will be completed, integrating the Betuweroute, but adding no real length to the ERTMS network, which totals still 340 km. Mistral programme continues renewing ATB systems on 20 corridors, that will be completed in 2018. When evenly divided over the years, 145 km of these corridors will be renewed by 2015, cumulating in a total of 200 km of renewd ATB tracks under the Mistral programme.

2018: no additional ERTMS infrastructure is foreseen. The second part of the ATB programme (20 corridors) will be completed, cumulating in 430 km of renewed ATB infrastructure under Mistral.

2020: the ERTMS connections from the ports of Amsterdam and Antwerp (port of Amsterdam, Amsterdam – Bijlmer, Utrecht – Geldermalsen and the "Iron Rhine") to the TEN network will be realised. Note that Utrecht – Geldermalsen is also part of the second part of the Mistral renewal programme, and has in the null alternative been fitted with new ATB equipment between 2013 and 2018. With the new ERTMS connections the ERTMS fitted network adds up to 430 km. The Mistral replacement programme on main railway lines continues with ATB renewals with about 40/45 km a year, cumulating in 520 km in 2020.

2028: no additions to the ERTMS network have taken place so the overall length is still 430 km. The ATB replacements are assumed to continue reaching 850 km in 2028.

2045: no additions to the ERTMS network have taken place so the overall length is still 430 km. The ATB replacements are assumed to continue, reaching 1570 km in 2045.

Rolling stock conversion in the null alternative

At the time of writing about 100 freight trains in the Netherlands are already equipped with ERTMS. Not all high speed trains are ERTMS equipped, but will be in 2010. Only the retrofit of ICE trains is uncertain. Apart from high speed and freight trains no large scale retrofit conversions are foreseen. However all *new* freight trains entering the Dutch market will be fitted with ERTMS. This holds for new trains replacing old rolling stock and new trains adding capacity to the fleet. As the rail cargo market is expected to grow significantly in the near future, so will the number of additional (ERTMS fitted) freight trains[48]. Furthermore international freight operators might see it appropriate to also retrofit existing rolling stock. As there are no indications to what extent retrofitting will take place, this is not taken into account in this study.

48 KiM (2007), *marktontwikkelingen in het goederenvervoer per spoor 1995-2020.*

Table 2.4: Summarizing table of rolling stock in the null alternative (number of trains)

Number of trains	2010	2013	2015	2018	2020	2023	2028	2045
Passenger trains in service (cum.)[49]	800	848	880	928	960	960	960	960
Of which								
ATB	754	802	834	882	914	914	914	914
ERTMS	46	46	46	46	46	46	46	46
Of which (additions per period)								
Natural replacements	0	0	0	0	0	0	0	0
Retrofit	27	0	0	0	0	0	0	0
Additional new	19	0	0	0	0	0	0	0
Freight trains in service	350	425	476	550	600	601	600	600
Of which								
ATB	250	225	213	194	181	163	131	25
ERTMS	100	200	263	356	419	438	469	575
Of which (additions per period)								
Natural replacements	6	18	13	18	13	19	31	106
Retrofit	94	0	0	0	0	0	0	0
Additional new	0	75	50	75	50	0	0	0

2010: 100 freight trains are equipped with ERTMS as well as 19 Fyra and 27 Thalys trains. ICE trains are not assumed to be ERTMS equipped in the null alternative, as it isn't clear if they will be ERTMS equipped, according to NS.

2013: all new freight trains that will have entered service will be ERTMS equipped (replacement of end of life rolling stock, as well as additional trains that are needed to meet growing demand), adding up to 190 ERTMS equipped freight trains. No changes in high speed and regular passenger trains.

2015: all new freight trains that will have entered service will be ERTMS equipped (replacement of end of life rolling stock, as well as additional trains that are needed to meet growing demand), adding up to 255 ERTMS equipped freight trains. No changes in high speed and regular passenger trains.

2018: all new freight trains that will have entered service will be ERTMS equipped (replacement of end of life rolling stock, as well as additional trains that are needed to meet growing demand), adding up to 350 ERTMS equipped freight trains. No changes in high speed and regular passenger trains.

2020: all new freight trains that will have entered service will be ERTMS equipped (replacement of end of life rolling stock, as well as additional trains that are needed to meet growing demand), adding up to 410 ERTMS equipped freight trains. No changes in high speed and regular passenger trains.

2028: all new freight trains that will have entered service will be ERTMS equipped (from 2020 onwards no additional growth is assumed so new trains are only replacement of end of life rolling stock), adding up to 460 ERTMS equipped freight trains. No changes in high speed and regular passenger trains.

2045: all new freight trains that will have entered service will be ERTMS equipped (from 2020 onwards no additional growth is assumed so new trains are only replacement of end of life rolling stock), adding up to 570 ERTMS equipped freight trains. No changes in high speed and regular passenger trains.

[49] Figure represents number of NS trains. Based on the overview by Spoorbranche/ProRail (2009), Materieeloverzicht, standdatum 11-12-2009 there are approximately 1450 trains currently in service in the Netherlands, of which approximately 800 are NS trains, 350 are freight trains and approximately 300 trains are in service for regional operations, foreign international operators, maintenance etc. As some trains have more than one traction unit and need more than one installation of signalling equipment, a total of 1750 ERTMS units is needed. NS states that primarily its VIRM and STM trains would have to be adapted to ERTMS, or some 750 units in total, out of a total of some 1100 units for 800 trains.

2.3 ERTMS Implementation Strategies

In the following sections three different implementation strategies are presented:

- Sectors strategy
- Natural implementation
- Upgrading (Roemer/Cramer alternative)

2.3.1 Sector Implementation strategy

The philosophy of this strategy is that all (or at least the majority of) rolling stock will be retrofitted with ERTMS, before ERTMS is implemented in the infrastructure. The infrastructure will be equipped with ERTMS level 2 "only" and existing systems will be removed at the same time[50]. This strategy corresponds to the sectors implementation strategy, as presented in 2006. Where new information on timing or costs is available, this information is taken into account. However the fundamentals of the strategy, including its phasing are unchanged. As the sectors strategy was written in 2006 the initial timetable is not feasible anymore. A five year period is taken into account for retrofitting rolling stock. As the conversion of rolling stock will begin when baseline 3 is available (2015), this means infrastructure will not be converted before 2020.

Infrastructural measures in the sectors strategy

Infrastructural measures in this strategy are described as follows:

- Implementation of ERTMS Level 2 baseline 3.
- Replacement of signalling systems in the infrastructure 2020 – 2043 from ATB to ERTMS L2 only (originally 2012 - 2035). On regional lines ERTMS components will be used[51].
- ERTMS implementation will be synchronised with (Mistral) natural replacements as much as possible (from 2020 onwards). In addition some "new" ERTMS signalling will be installed[52].

And, just as in the null alternative:

- Execution of "Mistral" (replacement programme of current end of life signalling systems, including outside elements). Short term (2010-2013) measures are described as "plateau 1". The second part (2018) is less strictly defined: upgrades in the signalling equipment are foreseen on 20 corridors, but the exact measures and their timing won't be specified by ProRail before early

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50 The sectors strategy (ProRail (2006), p.17) foresees additional costs for removing existing ATB systems when dual systems in the infrastructure are used, compared to its own preferred strategy (first rolling stock, then ERTMS only). This implicates that existing ATB systems will be removed when replaced directly by ERTMS "only".

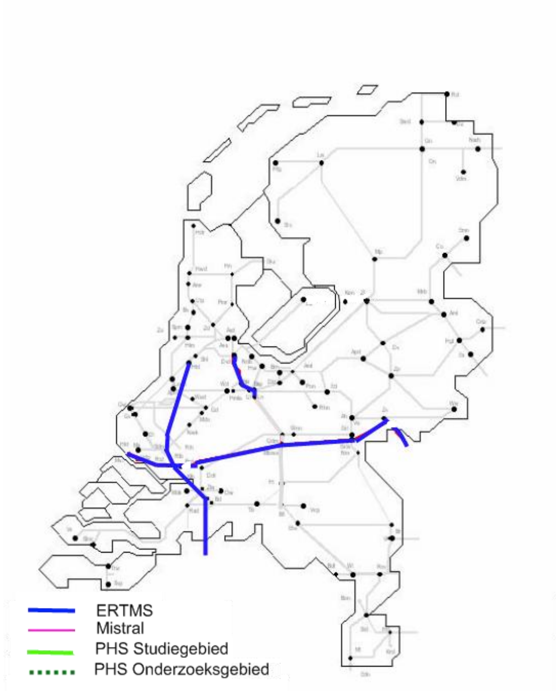
51 ProRail (2006). *Implementatiestrategie ERTMS,* See annex 4.

52 ProRail (2006). *Implementatiestrategie ERTMS.* Some of the explicitly named corridors (p.22) are not part of the Mistral programme, but are ERTMS equipped in the sectors strategy for reasons of capacity and interoperability. Also, in order to reach the situation depicted on p.7 of this report, "natural replacements" are not enough.

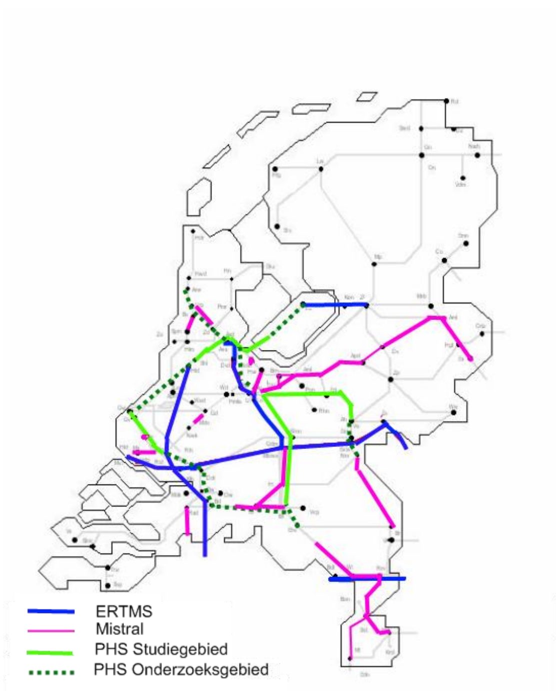
2010. After 2018 we assume that each year 2,5% of signalling systems in the network will be replaced.

- All measures that have already been planned in the long term Programme for Infrastructure, Spatial policy and Transport (MIRT) and the Programme High Frequency Rail transport “PHS” will take place. Other than that, no further network expansions are foreseen.

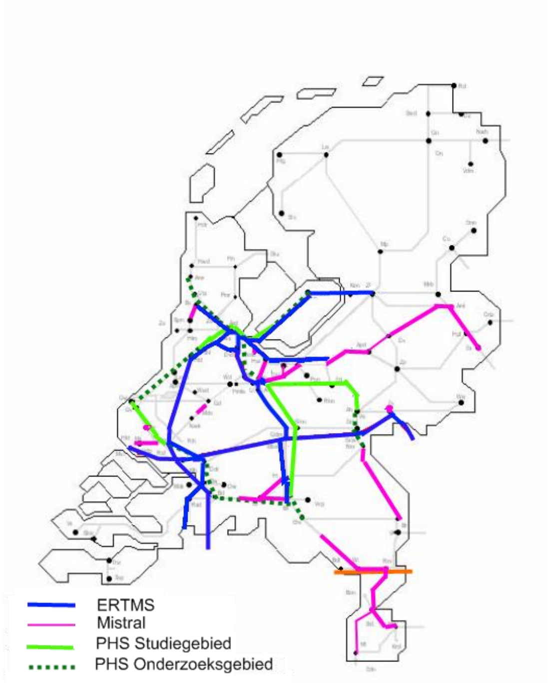
Sectors strategy 2010



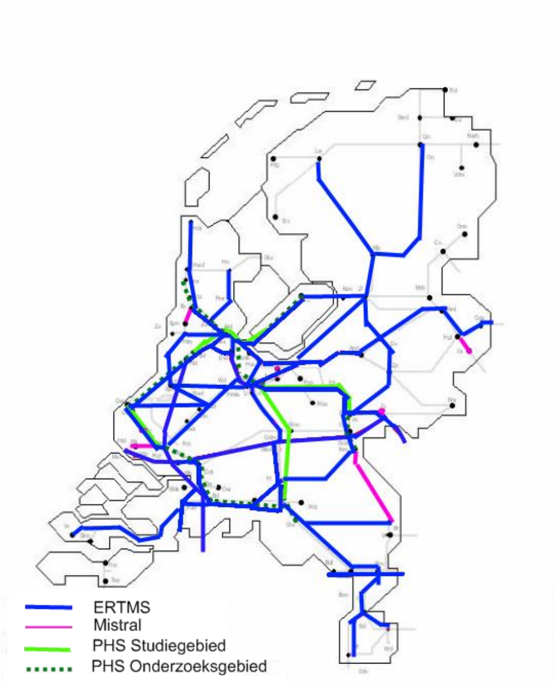
Sectors strategy 2020 (originally 2012)



Sectors strategy 2028 (originally 2020)



Sectors strategy final situation (approx. 2045)



From 2020 (originally 2012) onwards ERTMS “only” will be implemented in the infrastructure in this strategy. Originally Mistral replacements would be used for the replacement. As the sectors strategy is postponed in our analysis (waiting for the availability of baseline 3), this synchronization of Mistral and ERTMS in the period 2013 – 2018 is no longer possible (at least not without also postponing Mistral). In this period Mistral will take place as planned, replacing signalling equipment with ATB.

The 2028 map only shows the specified corridors that are mentioned in de 2006 strategy of the sector, to be equipped with ERTMS because of interoperability, high speed or capacity benefits. Other corridors in the original strategy where mentioned due to synchronization with natural replacements (Mistral), but postponement of ERTMS implementation makes this synchronization impossible. Therefore the 2028 map in this report differs from the 2020 map in the original sectors strategy.

The implementation of this strategy will be concluded in 2043. The final situation is depicted in the 2045 map. As the exact schedule of ERTMS implementation on the different corridors from 2028 is not specified, we assume that yearly costs between 2028 and 2043 are evenly divided over the remaining 15 years.

Table 2.5: Summarizing table of ERTMS infrastructure in the sectors strategy

Routelength (in km)	2010	2013	2015	2018	2020	2028	2045
Total length ERTMS routes (cumulative)	290	340	340	340	430	980	2000
New per period	290	50	0	0	90	550	1020
Of which							
ERTMS replacements (Mistral) per period						370	540
Other ERTMS investments per period	290	50			90	180	480
Total ATB replacements (Mistral) (cumulative)		55	200	430	520	480	0

2010-2020: as no ERTMS infrastructural measures are foreseen until 2020, the sector strategy is exactly the same as the null alternative until this year.

2028: ERTMS will have been implemented from 2020 onwards. An additional 550 km will be ready by 2028 if the total number of routekm in the final situation (2045) is distributed evenly over the period 2020 – 2045. Of these 550km, 230 kms have been explicitly specified as capacity and interoperability driven replacements in the sectors strategy (and are mostly not part of Mistral, except for 70 km (Baarn – Amersfoort, Uitgeest – Zaandam, Zevenbergen Roosendaal - border, Geldermalsen – Den Bosch)). Of these 550 km, a total of 370 km are assumed to be the ATB Mistral replacement programme in the null-alternative. A decrease in the cumulative number of ATB replacements, means that earlier ATB replacements are in this period equipped with ERTMS.

2045: the situation is equal to the final 2035 situation presented by the sector in 2006, cumulating in 2000 km of ERTMS routes, that will by this time all coincide with what would have been ATB Mistral replacements in the null alternative.

Rolling stock implementation in the sectors strategy

The complete fleet of rolling stock is going to be converted in the period from 2015 till 2020. All existing rolling stock will be retrofitted, and also new trains entering service to meet growing demand will be equipped with ERTMS (STM/ATB).

Table 2.6: Summarizing table of ERTMS rolling stock in the sectors strategy (number of trains)

Number of trains	2010	2013	2015	2018	2020	2023	2028	2045
Passenger trains in service (cum.)	800	848	880	928	960	960	960	960
Of which								
ATB	754	785	646	175	0	0	0	0
ERTMS	46	63	234	753	960	960	960	960
Of which (additions per period)								
Natural replacements	0	0	20	60	40	60	100	340
Retrofit	27	17	135	411	135	-60	-100	-340
Additional new	19	0	16	48	32	0	0	0
Freight trains in service	350	425	464	503	600	601	600	600
Of which								
ATB	250	225	171	27	0	0	0	0
ERTMS	100	200	293	476	600	600	600	600
Of which (additions per period)								
Natural replacements	6	18	13	18	13	19	31	106
Retrofit	94	0	30	90	61	-18	-32	-106
Additional new	0	75	50	75	50	0	0	0

2013: 17 ICE trains are ERTMS equipped, all else is the same as in the null alternative.

2015-2020: starting 2015 ERTMS equipped trains enter service at a rate of 20 natural replacements, about 130 retrofits yearly and 16 new additional trains for passenger services. For freight trains 6 trains are naturally replaced yearly and 25 additional trains enter service yearly (both also before 2015). Starting 2015 30 trains will be retrofitted yearly.

2020-2045: from 2020 onwards no additional new trains are assumed to enter service, so the absolute number of passenger and freight trains remains constant

2.3.2 The Natural implementation strategy 'simultaneous replacement'

This implementation strategy is devised by the ministry of transportation to capture benefits as soon as possible from ERTMS projects that will be realised the forthcoming years. These projects can incorporate either L2 or L1, either as "ERTMS only" or as dual signalling/overlay[53]. The projects involved have already been decided upon, are mandatory by European rules or have otherwise been (internationally) agreed upon. In order to capture the benefits of these investments, sufficient rolling stock has to be fitted with ERTMS as well (see section 2 of this document). Future Mistral and PHS projects may incorporate ERTMS deployment if there are benefits to be expected. This strategy is characterised as follows:

[53] There are some issues concerning the use of ERTMS functionality in a dual signalling/overlay situation. Internationally two approaches can be observed: 1) there are countries that do not accept contradictions between lineside signalling and DMI information. In this case there cannot be any lineside signalling or it has to be switched off for level 2 trains; and 2) there are countries that accept contradictions. In this case "the DMI information has always precedence over lineside signalling" (e.g. Austria, Spain) note: this may also apply to Level 1. There are very few lines with dual fitment. The Mattstätten-Rothrist line in Switzerland can be operated with lineside signalling only OR with Level 2 only. Other lines accept both. The best example is probably Germany (and Austria). In these countries speeds over 160 km/h require cab signalling. For the driver, LZB (Linienzugbeeinflussung) looks very similar to Level 2. There are some thousands of line kilometers equipped with both conventional lineside signalling + PZB (punktförmige Zugbeeinflussung) and LZB. In conclusion having both systems is technically possible, but using both systems at the same time might have practical problems.

- Implementation of ERTMS Level 2 baseline 3. This means implementation starts from 2015 (preparations can start in 2013).
- From 2015 ERTMS will be implemented on Mistral corridors where the benefits for passengers and shippers are expected to be high. Initially 50% of Mistral corridors will be fitted with ERTMS counting up to 100% once enough rolling stock is fitted.
- Conversion of rolling stock starting as soon as possible for Amsterdam – Utrecht and Hanzelijn (both 20 trains), and after 2015 all natural replacements will be fitted with ERTMS.
- For running dedicated ERTMS services on designated corridors, and therefore making ERTMS "only" a possibility NS needs to segregated its fleet over ERTMS and ATB operations. According to NS 50%-70% of rolling stock needs to be equipped with ERTMS[54].

And, just as in the null alternative:

- Execution of "Mistral" (replacement programme of current end of life signalling systems, including outside elements). Short term (2010-2013) measures are described as "plateau 1". The second part (2018) is less strictly defined: upgrades in the signalling equipment are foreseen on 20 corridors, but the exact measures and their timing will not be specified by ProRail before early 2010. After 2018 we assume that each year 2,5% of signalling systems in the network will be replaced.
- As the exact content of the Mistral programme is unknown, especially for the long term, we assume that each year 2,5% of signalling systems in the network will be replaced.
- All measures that are already planned in the long term Programme for Infrastructure, Spatial policy and Transport (MIRT) and the Programme High Frequency Rail transport "PHS" will take place. Other than that, no further network expansions are foreseen.
- ERTMS will be implemented on routes if it is mandatory or otherwise (internationally) agreed upon.

Infrastructural measures in the natural replacement strategy

Up to 2015 the infrastructural measures in this strategy are equal to the measures in the null alternative. In the period 2015 – 2018 a part of Mistral can be used for ERTMS implementation. When expanding the ERTMS network on the busiest corridors, of which parts are already fitted with ERTMS equipment, corridors like Utrecht – Amersfoort – Apeldoorn and Utrecht – Den Bosch (- Tilburg) are options for ERTMS implementation[55]. Also Apeldoorn – Amersfoort – Utrecht, and Geldermalsen – Den Bosch – Tilburg can be equipped with ERTMS, as these corridors connect to existing ERTMS routes. Furthermore these routes create possibilities for combining the ERTMS implementation with (parts of) the PHS programme or with the connection of the Hanzelijn (via Zwolle – Apeldoorn) to the ERTMS network.

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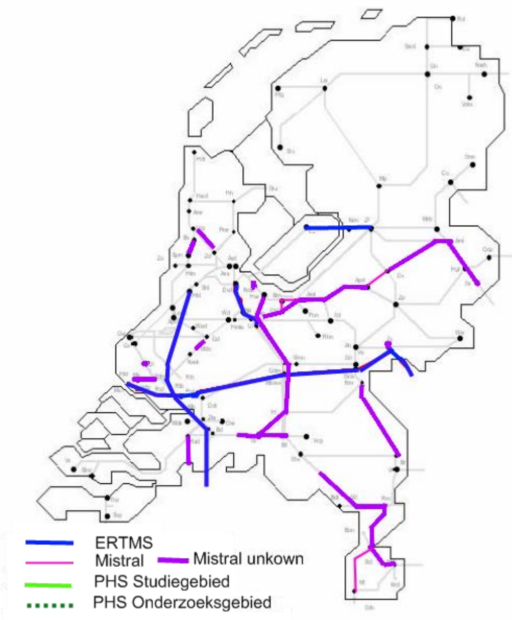
[54] NS indication given by e-mail, November 11, 2009.

[55] Utrecht – Geldermalsen (part of the Utrecht-Den Bosch track) is in the null alternative part of the port of Amsterdam – Betuweroute connection that is to be fitted with ERTMS in 2020. In this strategy this connection will already be fitted with ERTMS in 2018, simultaneously with the Mistral replacements.

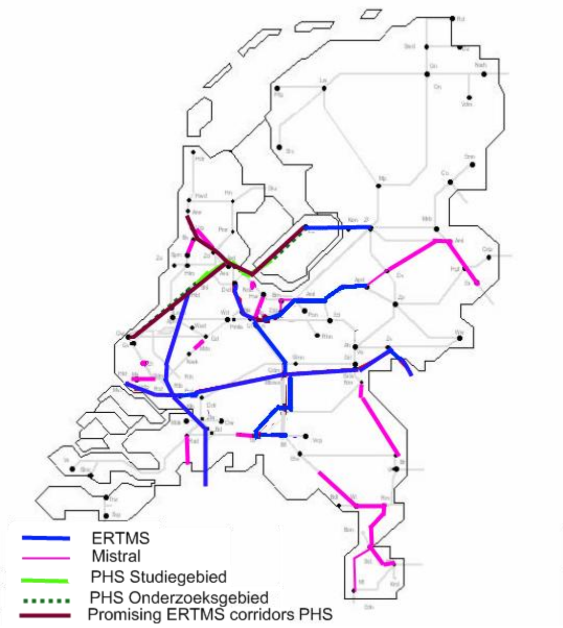
There are also possibilities for ERTMS implementation in combination with PHS. ERTMS can even save costs on infrastructural measures in PHS (see box). In PHS two scopes are studied (called ‘studiegebied’ and ‘onderzoeksgebied’). The smaller scope (studiegebied) focuses on specific corridors: Almere - Schiphol, Utrecht – Arnhem, The Hague – Rotterdam and the corridor Utrecht Den Bosch – Boxtel, which is also part of Mistral (from Utrecht to Den Bosch). The larger scope is broader. At the time of writing not all measures in PHS are specified.

If the broader scope mentioned in PHS will be equipped with ERTMS, the ERTMS network will incorporate Amsterdam – Schiphol – Leiden - The Hague – Rotterdam – Breda – Tilburg – Eindhoven – Den Bosch – Utrecht – Amsterdam. Also Arnhem, Zwolle, Lelystad, Almere, Alkmaar and Zaandam will be connected to this network. However, if ERTMS will only be implemented in the narrower scope, there will not be a network of connected ERTMS routes.

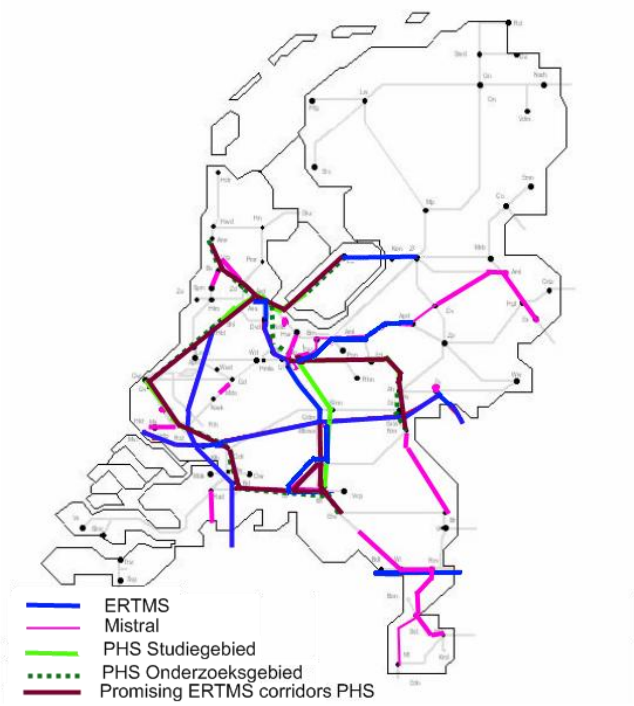
Natural replacement 2015



Natural replacement 2018



Natural replacement 2020



After 2020 we assume that Mistral replacement of signalling installations continues at a rate of 2,5 percent of the network yearly. This can be done with either dual signalling installations or ATB installations. The assumption is that initially 50% of all replacements will be fitted with ERTMS as a dual signalling system. When sufficient rolling stock will be available (85% is assumed), 100% of all replacements will be equipped with ERTMS "only".

Table 2.7: Summarizing table of ERTMS infrastructure in the natural replacement strategy

Routelength (in km)	2010	2013	2015	2018	2020	2028	2045
Total length ERTMS routes (cumulative)	290	340	340	465	588	753	1409
New per period	290	50	0	125	123	165	699
Of which							
ERTMS replacements (Mistral) per period				125	58	165	699
Other ERTMS investments per period	290	50			65		
Total ATB replacements (Mistral) (cumulative)		55	200	305	363	528	591

2010-2015: the infrastructure does not differ from the null alternative up to 2015.

2018: from 2015 onwards approximately 50% of Mistral corridors will be fitted with ERTMS, adding up to 125 km additional ERTMS routes (part of Mistral plateau 2 & 3, including Utrecht – Geldermalsen) will be ready. Utrecht - Geldermalsen is mentioned specifically, as it is part of the connection from the port of Amsterdam to the Betuweroute that is planned for 2020 in the null alternative. This connection will be ready earlier in this strategy.

2020: the replacements continue at 50/50 ATB/ERTMS rate. The ERTMS replacements are half of the 115 km ATB replacements in the null alternative (the difference of total ATB replacements from 2018 in the null alternative being 90, because in the same period 25 km of earlier ATB replacements is equipped with ERTMS). The additional new ERTMS fitted infrastructure is 25 km less then in the null alternative, because Utrecht - Geldermalsen was ERTMS equipped at an earlier stage.

2028-2045: from 2020 onwards the ERTMS replacements will continue. From 2030 onwards 100% of all natural replacements will be ERTMS "only" fitted as in this year enough rolling stock will be available (assuming an initial partial fleet of 50% will be built up form 2015-2020). This cumulates in an additional 1409 km of ERTMS routes in 2045.

Rolling stock implementation in the natural replacement implementation strategy

In 2010 the Amsterdam – Utrecht corridor will have operational ERTMS (v.2.3.0d). As the objective of this strategy is to make efficient use of investments in ERTMS that have already taken place, sufficient rolling stock has to be ERTMS equipped to run train services under ERTMS on these tracks. This causes the need to dedicate the ERTMS equipped fleet to the ERTMS lines. This situation deviates from the current NS operating procedures. These rely on a maximum flexibility and the use of standardized trains. In order to have benefits from ERTMS on specific corridors, NS states that a minimum of 50% to 70% of all rolling stock needs to be equipped. In our analysis, calculations are made starting with 0% (no ERTMS rolling stock), 30%, 50% and 70% ERTMS rolling stock (retro)fitted before capturing benefits (see box for international references on this issue). Because a segregated fleet reduces overall operational flexibility, there is a need for additional rolling stock[56].

In the years following we assume natural replacements in the passenger fleet (2,5% of the existing fleet per year), as well as additional new rolling stock to meet growing demand (an additional 2% per year from 2010 till 2020) will be equipped with ERTMS. Once enough rolling stock will be equipped for running ERTMS only on certain relations, ERTMS only will be implemented. For freight trains there is no difference from the null alternative.

56 The number of additional rolling stock needed is not straightforward. ProRail (2006) assumes an additional 5% of rolling stock is needed to allocate partial fleets to designated ERTMS corridors. Arcadis (2007) assumes additional costs of € 100 million.

Box: Segregated fleet

Internationally different approaches exist. Both Denmark and UK have chosen to equip rolling stock first before fitting tracks with ERTMS (comparable to the sectors strategy). Switzerland has chosen a more gradual approach. In Denmark the complete fleet will be equipped before deployment starts on the infrastructure (except for early deployment schemes on branch lines). In the UK, rolling stock is attributed to a TOC (Train Operating Company) and therefore runs generally in a well defined area. Therefore rolling stock will be equipped first, but only the fleets related to the next infrastructure phase.

In the Netherlands the situation is very different form the UK. Rolling stock is operated on large parts of the network and is for a large part interchangeable between routes and services. A partial fleet fitment will mean a loss of flexibility and train operators are very reluctant to segregated their fleet and reduce the number of units at their disposal.

In Switzerland the first section to be equipped with Level 2 was Zofingen-Sempach on the Olten-Lucerne line. For this line a minimum of units was equipped with ERTMS. This can be considered as a regional line although it can be used by freight transit. 63 engines were equipped by Bombardier for this pilot line. However, the ETCS Level 2 equipment was subsequently dismantled and new lineside signalling installed. Reasons given were:

- Cost of upgrading to the then applicable version of subset 026 (V2.2.2)
- Planned use by IC trains Genève-Lucerne.

For the second project in Switzerland Mattstätten-Rothrist, on-board equipment was ordered for 460 trains or locomotives. This project is a new section between Berne and Olten on the backbone of the Swiss network (from Berne to Basle and Zurich). Furthermore regional trains do not run on Mattstätten-Rothrist. Motive stock of SBB is around 1350, including diesel locomotives but excluding small shunting engines. By 2006 630 Swiss engines (not only SBB) were equipped with ETCS. The Lötschberg base tunnel has also Level 2 only. There are other important lines (Geneva to Basle and Zürich via Biel/Bienne, Geneva to Simplon and Basle to Gotthard) that accept non-equipped rolling stock.

What would be an absolute minimum of rolling stock to run 100% ERTMS on designated corridors in the Netherlands, and thus be able to have ERTMS only infrastructure? We use the current situation on the Amsterdam - Utrecht line as an example. This track section is used by trains running the following services:

- ☐ Alkmaar - Maastricht (intercity 2x per hour)
- ☐ Schiphol – Maastricht (intercity 2x per hour)
- ☐ Nijmegen – Den Helder (intercity 2x per hour)
- ☐ Nijmegen – Schiphol (intercity 2x per hour)
- ☐ Enkhuizen - Amsterdam – Gouda – Rotterdam centraal (sprinter 2x per hour)
- ☐ Breukelen – Utrecht centraal (sprinter 2x per hour)
- ☐ Breukelen – Rhenen (sprinter 2x per hour)
- ☐ One ICE train every two hours
- ☐ Maximum of two freight trains every hour

Limiting the assessment to NS passenger trains, the calculation is as follows:

- ☐ 8 intercity trains per hour in each direction wit a turnaround time of ca 3,5 hour, means 16 * 3,5 = 56 trains needed
- ☐ 2 sprinters per hour in each direction with a turnaround time of 2,5 hour, means 4 * 2,5 = 10 trains
- ☐ 4 sprinters with a turnaround time of 1 uur = 8 trains

This adds up to a total of 74 NS passenger trains using the Amsterdam – Utrecht corridor in the current situation. With PHS this number will increase with over 50 percent. Extra capacity needed to allow for servicing, maintenance and break downs, should further be added to this number. And an extra addition to allow compensate for the reduction of operational flexibility.

Table 2.8: Summarizing table of ERTMS rolling stock in the natural replacement strategy (50%)[57]

Number of trains	2010	2013	2015	2018	2020	2023	2028	2045
Passenger trains in service (cum.)	800	848	880	928	985	985	985	960
Of which								
ATB	734	657	594	466	448	388	288	73
ERTMS	66	191	286	462	537	597	697	887
Of which (additions per period)								
Natural replacements	0	60	40	60	20	60	100	340
Retrofit	47	17	23	68	23	0	0	-150
Additional new	19	48	32	48	32	0	0	0
Surplus capacity					25			-25
Freight trains in service	350	425	476	550	600	600	600	600
Of which								
ATB	250	225	213	194	181	163	131	25
ERTMS	100	200	263	356	419	438	469	575
Of which (additions per period)								
Natural replacements	6	18	13	18	13	19	31	106
Retrofit	94	0	0	0	0	0	0	0
Additional new	0	75	50	75	50	0	0	0

No differences in freight trains compared to the null alternative.

2010: 20 ERTMS passenger trains will come into service on the Amsterdam / Utrecht line.

2013: all new rolling stock (additional capacity and replacements) will be ERTMS equipped and be deployed as much as possible on Amsterdam-Utrecht and the Hanzelijn, which is ready in 2013. Also 17 ICE trains will be ERTMS fitted.

2015-2020: after 2015 (with the availability of baseline 3) all new rolling stock (additional capacity and replacements) will be ERTMS equipped. The early ERTMS equipped fleet will be upgraded. Also from 2015 onwards, rolling stock is retrofitted to achieve a minimum of (in this example) 50% of rolling stock over a period of 5 years. As a compensation for the loss of flexibility in operations 25 additional units are assumed (comparable to the Arcadis figure).

2020-2045: yearly replacements will continue as planned.

2.3.3 Upgrading: the Roemer/Cramer initiative

The representatives Roemer and Cramer put forward a strategy where investments in ERTMS would start as soon as possible in order to capture benefits early and possibly reduce other investments in infrastructure. In this SCBA this strategy is comparable to the sectors strategy, with a single difference: timing. This means investments in rolling stock will take place starting in 2012, and infrastructure investments five years later. Starting early implies also that baseline 3 version of level 2 is not yet available. Early investments (before 2015) are therefore in the current version of L2, 2.3.0d. To be compatible with baseline infrastructure that will be rolled out after 2015, there is a need to update all v2.3.0d rolling stock after 2015.

Infrastructural measures in the “upgrading” strategy

Infrastructural measures in this strategy are described as follows:

- Implementation of ERTMS Level 2 baseline 3 (available when rolling stock is converted).

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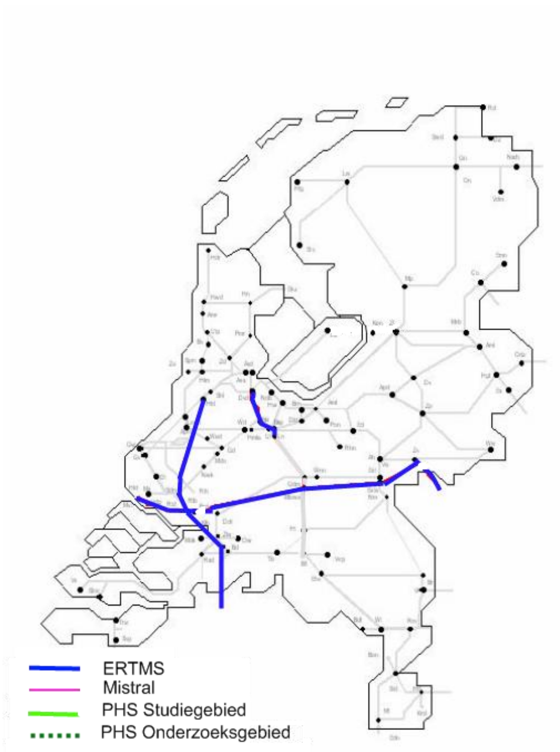
[57] Table represents figures that add up to an ERTMS fleet of 50% of all rolling stock in 2015.

- Replacement of signalling systems in the infrastructure 2017 – 2040 from ATB to ERTMS L2 only (originally 2012 - 2035). On regional lines ERTMS components will be used[58].
- ERTMS upgrades will be synchronised with (Mistral) upgrades as much as possible. In addition some “new” ERTMS signalling will be installed.
- By starting earlier, synergy with the PHS programme is possible.

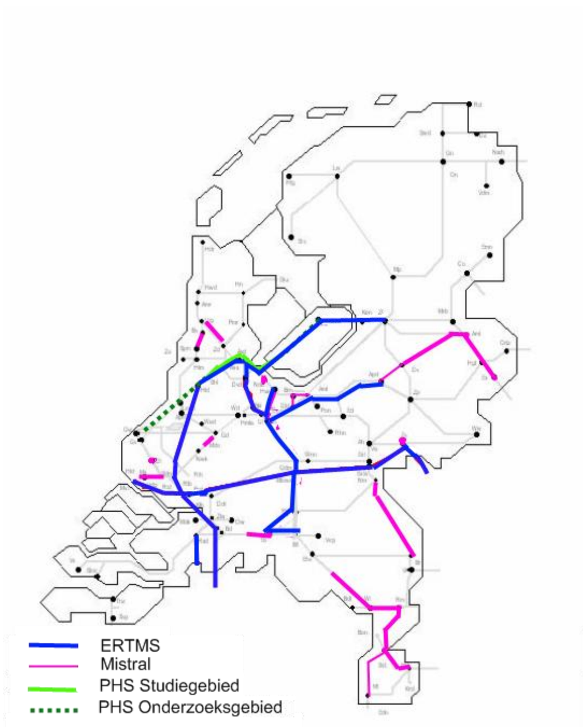
And, just as in the null alternative:

- Execution of “Mistral” (replacement programme of current end of life signalling systems, including outside elements). Short term (2010-2013) measures are described as “plateau 1”. The second part (2018) is less strictly defined: upgrades in the signalling equipment are foreseen on 20 corridors, but the exact measures and their timing will not be specified by ProRail before early 2010. After 2018 we assume that each year 2,5% of signalling systems in the network will be replaced.
- All measures that are already planned in the long term Programme for Infrastructure, Spatial policy and Transport (MIRT) and the Programme High Frequency Rail transport “PHS” will take place. Other than that, no further network expansions are foreseen.
- ERTMS will be implemented on routes if it is mandatory or otherwise (internationally) agreed upon.

Upgrading 2010

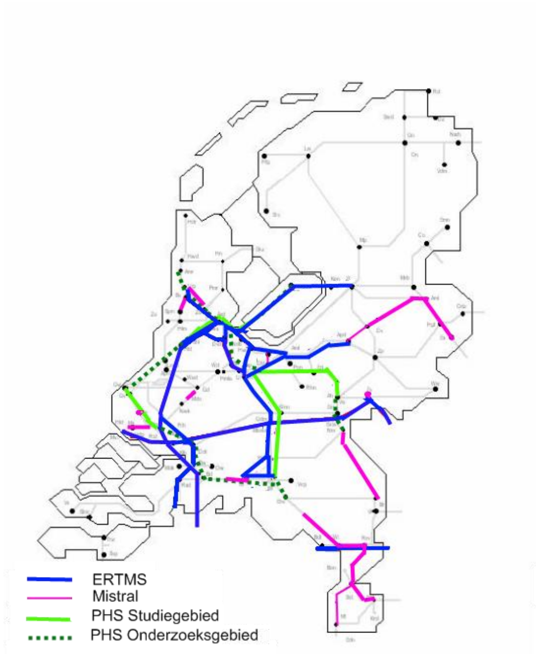


Upgrading 2018

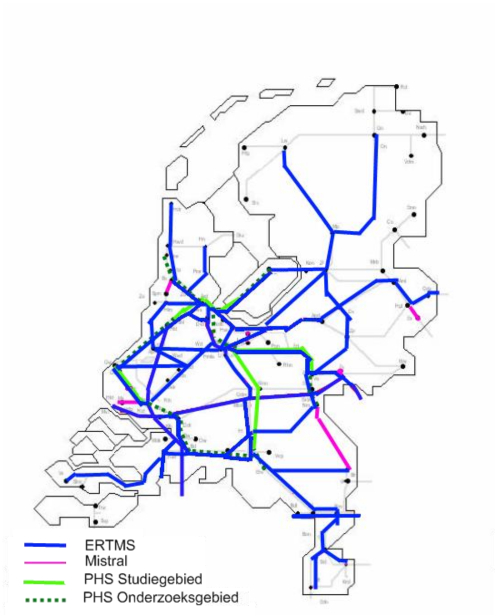


58 ProRail (2006). *Implementatiestrategie ERTMS*, See annex 4.

Upgrading 2023



Upgrading (approx. 2045)



From 2015 onwards ERTMS "only" will be implemented in the infrastructure in this strategy. In contrast to the (postponed) sector strategy, starting early means there are more possibilities for the synchronization of Mistral and ERTMS in the period 2015 – 2018.

The implementation of this strategy will be concluded in 2040. The final situation is depicted in the 2045 map.

Table 2.9: Summarizing table of ERTMS infrastructure in the "upgrading" (Roemer/Cramer) strategy

Routelength (in km)	2010	2013	2015	2018	2020	2028	2045
Total length ERTMS routes (cumulative)	290	340	340	480	700	1095	2000
New per period	290	50	0	140	220	395	905
Of which							
ERTMS replacements (Mistral) per period				75	115	330	705
Other ERTMS investments per period	290	50		65	105	65	200
Total ATB replacements (Mistral) (cumulative)		55	200	355	355	355	0

2010-2015: until 2017 no investments in infrastructure are foreseen, other than those in the null alternative

2018: as rolling stock is converted in the period 2012-1017, in 2017 the ERTMS investments in the infrastructure start. As the same phasing as in the sectors strategy is used, this leads to 75 kms of ATB replacements and another 65 kms that are not part of the ATB replacement programme.

2020 -2045: the ERTMS replacements continue at the same pace.

Rolling stock implementation in the "upgrading" strategy

The complete fleet of rolling stock will be converted in the period from 2012 till 2017. All existing rolling stock will be retrofitted, and also new trains entering service to meet growing demand will be equipped with ERTMS (STM/ATB). As a lot of new rolling stock is expected to enter service the forthcoming years, this strategy offers more possibilities to order new trains fitted with ERTMS then the sectors strategy. In the sectors strategy these trains are assumed to be ATB equipped, than later (when baseline 3 is ready) be equipped with ERTMS (retrofit).

Table 2.10: Summarizing table of ERTMS rolling stock in the "upgrading" (Roemer/Cramer) strategy

Number of trains	2010	2013	2015	2018	2020	2023	2028	2045
Passenger trains in service (cum.)	800	848	880	928	960	960	960	960
Of which								
ATB	754	640	225	0	0	0	0	0
ERTMS	46	208	655	928	960	960	960	960
Of which (additions per period)								
Natural replacements	0	20	40	60	40	60	100	340
Retrofit	27	126	375	165	-40	-60	-100	-340
Additional new	19	16	32	48	32	0	0	0
Freight trains in service	350	325	376	550	600	601	600	600
Of which								
ATB	250	83	0	0	0	0	0	0
ERTMS	100	242	376	550	600	601	600	600
Of which (additions per period)								
Natural replacements	6	18	13	18	13	19	31	106
Retrofit	94	42	71	81	-13	-18	-32	-106
Additional new	0	75	50	75	50	0	0	0

2013: Retrofitting of rolling stock starts from 2012 onwards. In addition all new rolling stock will be ERTMS fitted, as well as 17 ICE high speed trains.

2018: In 2018 all rolling stock is ERTMS fitted, adding up to 928 ERTMS passenger trains and 550 freight trains.

2020: Due to expected growth in demand, total numbers of rolling stock are further increasing.

2023-2045: Total number of rolling stock remains constant.

3 Costs of implementing ERTMS

One of the main issues of the ERTMS implementation are the costs. A difficulty with assessing the costs of ERTMS, is that much of the ERTMS equipment addressed in this study is in its developing stages or is not yet available on the market. Adding to the complexity is that empirical data is based on current versions that are, or were, in their developing stages, and or adapted to specific situations. In this chapter we start with an overview of cost figures used in earlier studies, address expected price and market developments and conclude with the costs used in this study in the different strategies.

3.1 Cost figures used in earlier studies

3.1.1 Overview of cost calculations

Since the publication of the sectors strategy, different studies have shown different cost estimates of various ERTMS related cost components. In table 3.1 an overview is presented of the nominal costs calculated in previous studies for the sector strategy[59].

Table 3.1: Bandwidth of nominal costs for the sector strategy

	Sector implementation strategy 2006	**BAH audit strategy 2007**	**Arcadis 2nd opinion 2007**
Retrofit rolling stock	280 mio	336 mio	353 mio
ERTMS implementation new rolling stock		-	22 mio
Upgrade baseline 3		-	50 mio
Leasing extra rolling stock		-	30 mio
Subtotal rolling stock	**280 mio**	**336 mio**	**455 mio**
Savings on infrastructure	-170 mio	-1000 mio	-
Implementing ERTMS L2 in complete network	600 mio	600 mio	1313 mio
Conversion signalling installations ('08-'13)			180 mio
Investments in GSMR needed	-	50 mio	-
Subtotal infrastructure	**430 mio**	**-350 mio**	**1493 mio**
Total	**710 mio**	**-14 mio**	**1948 mio**

Source: Ministry of Transport Public Works and Water Management, ProRail, BAH, Arcadis

The overall bandwidth of the figures in the table implies that ERTMS implementation following the sector strategy could be either beneficial from a pure financial point of view or cost up to 1,95 billion euro's. This is a clear indication of the uncertainties that exist in the cost estimations, especially in infrastructure costs[60]. Since the publication of the reports referred to in table 3.1, ProRail has

59 See Appendix A for a more comprehensive overview of cost figures used in different studies.

60 Note that infrastructure costs in this overview is calculated for 3250 routekm/6500 trackkm. BAH states that ProRails estimate is "conservatively high" and that these costs could very well be 20%-30% lower.

gained new insights in different costs components, which are included in its business case for the MISTRAL programme.

At the time of publication of the sectors implementation strategy, there was limited experience with the actual costs of ERTMS. Also this study does not mention any costs of replacing the conventional b-relay interlockings by electronic interlockings[61]. In addition, maintenance costs of outside signals have fallen since LED technology is being used. Evidence from Switzerland shows that 2006 cost figures were optimistic. Costs for ERTMS implementation on corridors calculated in 2008 are estimated to be 1.5 to 2.5 times higher than estimated in 2006[62].

According to the experts drawing up the ProRail business case for Mistral, the expected costs of implementing L2 ERTMS in the Netherlands is significantly different from the estimates in the implementation strategy of 2006, when cost of electronic interlockings are taken into account. The ATB system is based on B-relay technology, where ERTMS Level 2 is until now only compatible with electronic interlockings[63]. In the business case the costs for implementing ERTMS Level 2 compatible interlockings on 75% of the Dutch network are estimated at almost € 2 bn. The costs of renewing signalling systems, with ATB B-relay technology, are estimated at around € 0.7 bn[64]. The difference of € 1.3 bn is attributed for €0.8 bn to the more expensive interlockings and for around € 0.5 bn to actual ERTMS components[65]. In the Mistral programme it is possible to make replacements using electronic interlockings combined with ATB. By doing so, future ERTMS upgrades might be far less costly, but the actual costs of the Mistral programme go up, from the mentioned € 0.7 bn for replacements with ATB based on B-relays to an expected € 1.5 bn for replacements with ATB based on electronic interlockings (see table 3.2).

The differences between ERTMS and ATB in costs of ‘outside elements like balises, signals, switch control boxes and cables, are smaller than the differences between the interlockings. On the one hand ERTMS can save costs. As European standardized components like balises are used and with L2, signals become redundant. On the other hand computer based technology is in many cases more expensive. Also labour costs (like digging cables and connecting the equipment), are responsible for a large part of the costs. For replacing 75% of the ‘outside elements’ in the network, ProRail estimates ERTMS implementation to be around € 100 mio more expensive than just renewing the ATB

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61 Arcadis calculates different costs for signalling replacements including interlockings from 2000 mln to 3400 mln, but this difference is attributable to the scope of these replacements (1/3 or the whole of the network), not to technology used.

62 Bundesamt für Verkehr BAV (2008), *European Train Control System ETCS*, Standbericht Nr. 2008.

63 Developments are currently taking place to combine ERTMS L2 with B-relay interlockings.

64 ProRail (2009), *Financiële analyse, Bijlage 1 bij Business Case Mistral Integrale Vervanging & ERTMS*, all figures are nominal non discounted costs.

65 ProRail (2009), *Financiële analyse, Bijlage 1 bij Business Case Mistral Integrale Vervanging & ERTMS*, all figures are nominal non discounted costs.

system based on B-relay technology (€ 2.3 vs. 2.2 bn).[66] However, if B-relays are replaced by electronic interlockings and ATB, these costs are estimated at € 2.7 bn as cost savings by using standardized components or removing signals are not possible and more expensive technology is used.

Table 3.2: ProRail MISTRAL estimates of ERTMS infrastructure investments and Mistral replacements with ATB[67]

	B-relay, ATB	Electronic Interlockings, ATB	ERTMS L2
Interlockings	700 mio	1,500 mio	2,000 mio
External components	2,200 mio	2,700 mio	2,300 mio
Total @ 75% of network	**2,900 mio**	**4,200 mio**	**4,300 mio**
Total @100% of network (incl economies of scale)	**3,900 mio**	**5,200 mio**	**5,300 mio**

Source: ProRail

The total costs of ERTMS implementation on 75% of the Dutch railway infrastructure count up to €4.3 bn Euro. Replacing the ATB system without implementing ERTMS costs around €2.9 bn if B-relay interlockings are used, and €4.2 bn if electronic interlockings are used.

Note that ProRail Mistral figures are for 75% of the network, and therefore match with the scope of this study. Arcadis, the sectors strategy and BAH calculated figures for the complete Dutch network (100% of all tracks). Arcadis estimated the costs of ERTMS Level 2 implementation in the infrastructure at 4.9 bn Euro, of which replacing the signalling system in the complete Dutch network (including electronic interlockings but without ERTMS) were estimated at € 3.4 bn[68], leaving € 1.5 bn for ERTMS implementation as mentioned in table 3.1. To compare this figure to the ProRail Business case figures we need to derive total network cost. ProRail states that probably some economies of scale are expected using modern technology. The costs of ERTMS L2 implementation would be around € 5.3 bn, and of ATB replacement using electronic interlockings around € 5.2 bn for the complete Dutch network[69]. For ATB with B-relay interlockings this would add up to 3.9 bn (no economies of scale). Where the sector and BAH estimated approximately € 600 mio (excluding savings on infrastructure) and Arcadis approximately € 1,500 mio for ERTMS infrastructure investments compared to ATB replacements, the more recent ProRail figures indicate that this could be in the range from € 100 mio if compared to a situation where Mistral has replacements with electronic interlocking and ATB, to € 1,400 mio when compared to replacements with B-relays and ATB.

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66 ProRail (2009), *Financiële analyse, Bijlage 1 bij Business Case Mistral Integrale Vervanging & ERTMS*, all figures are nominal non discounted costs.

67 ProRail distinguishes costs for initial investments, conversion to L2, maintenance and other adaptations. Figures in this table represent only initial investments.

68 Arcadis (2007), Second opnion ERTMS implementatieplan en 160 km/u.

69 Interview ProRail.

Cost estimates of rolling stock investments also differ, but not as widely as the estimates in infrastructure. To gain some more insight in the cause of the differences observed, we discuss unit costs in the next section.

3.1.2 Unit costs

Table 3.3 gives a summary of unit costs for L2 equipment in rolling stock and infrastructure as observed by Arcadis in their second opinion on the sectors strategy.

Table 3.3: Unit costs per trackkm (infrastructure) and train (rolling stock)

Cost component	UNIFE/Siemens [k€]	EC [k€]	ARCADIS 2nd opinion sector strategy[k€]	Sectors strategy ProRail (2006) [k€]
ROLLING STOCK				
Level 1 retrofit existing rolling stock with ERTMS and ATB STM	270	260 - 300	203	passenger train:150 (min) – 250 (max) cargo train: 290 (min) – 320 (max);
Level 1 new rolling stock with ERTMS and ATB STM	92	90-100	92	
Level 2 retrofit retrofit existing rolling stock with ERTMS and ATB STM	320	300 - 350	240	
Level 2 new rolling stock with ERTMS and ATB STM	125	120-140	125	
Upgrade rolling stock SRS2.3.0 naar SRS 3.0.0 (Level 2)	--	--	€ 50 Mio	0
Additional rolling stock needed for segregated operations (Level 1 en 2)	--	--	€ 100 Mio	€ 280 Mio
INFRASTRUCTURE				
Conversion signalling installations to dual signalling/overlay Level 2	--	--	PM	€ 75 Mio
Implementation ERTMS Level 1	102 per km	100 per km	43 per km	52 per km
Implementation ERTMS Level 2	312 per km	200 per km	202 per km	100 per km
Costs of replacing signalling installations (2008 – 2038) Level 2	--	--	€ 3400 Mio	--
Conversion signalling installations (2008-2013) to ERTMS Level 2	--	--	€ 180 Mio	0

Source: Arcadis

The table illustrates that cost estimates are uncertain. Also, the studies are not clear on the economies or diseconomies that can be obtained in combining ERTMS implementation in combination with the Mistral programme. As mentioned in the previous section, this is a complex issue, in which technical (im)possibilities of combinations of ERTMS with B-relay and ATB with electronic interlocking play an important role. As this is an important uncertainty in the recent findings of ProRail in their business case, we present the differences between the Arcadis estimates and the ProRail figures in table 3.4.

Table 3.4: Comparison of unit costs for infrastructure upgrades

	Arcadis k€/trackkm	ProRail business case k€/trackkm
ATB with B-relay interlockings		575[70]
ATB with electronic interlockings	520[71]	860[72]
ERTMS L2	722[73]	880[74]
ERTMS L2 overlay	774[75]	995[76]

Box: relay technology and electronic interlockings

The Dutch signalling system relies on B-relay technology. B-relay technology has disadvantages on complex junctions. For each single track junction a relay contact is needed. On a large junctions there can be hundreds of these. To reduce costs NS started some 25 years ago by implementing electronic interlockings on stations. Cost savings in design, implementation and maintenance were extensive. In other countries the situations is similar: electronic interlockings are used on junctions. In the daily operation of the railway system, the correct function of junctions is of vital importance. On the open track B-relay technology is and was used, because of its main characteristics (adequate for the functional job, cheap and very robust).

With the arrival of ERTMS level 2, electronic interlockings are also applied on the open track. Sophisticated technology is used to do a relatively simple job. In addition, electronics are far more vulnerable to outside conditions than B-relay technology. Both factors raise costs. These high costs would be solved with the coming of level 3, but possibly an earlier solution will be at hand shortly. Suppliers are testing the possibilities to reduce these costs by integrating B-relay technology with ERTMS L2 functionality.

3.1.3 Cost drivers

Cost experts at both supply and demand side state that costs observed until now are probably relatively high. Reasons given for these high cost levels are:

- New technology: ERTMS is still in its developing stages.
- Projects carried out are most of the time relatively small projects
- Economies of scale have not been captured

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70 Derived from 2.9 bn for 75% of the network (see table 3.2)

71 Derived from 3400 mln for the whole network, for 6500 trackkm.

72 Derived from 4.2 bn for 75% of the network (see table 3.2)

73 520 for electronic interlockings and an additional 202 for ERTMS L2.

74 Derived from 4.3 bn for 75% of the network (see table 3.2)

75 Not explicitly specified by Arcadis. Figure is the sum of 520k€ for ATB B-relay combined with 202 k€ for ERTMS L2 implementation + 52 k€ for adapting signalling installations (10% of 520 k€, according to Arcadis).

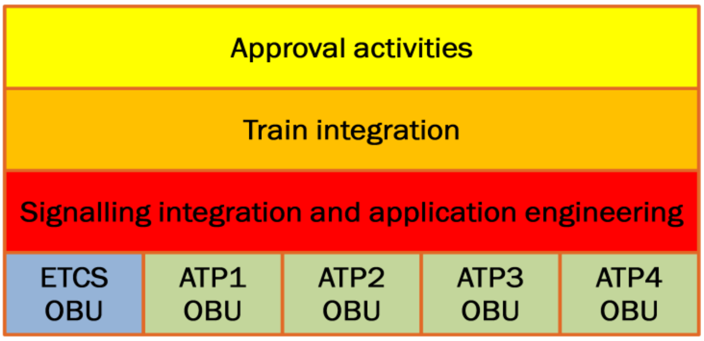
76 Based on 5,5 mln for the Amsterdam-Utrecht line, the costs of just implementing ERTMS are approximately 45 k€ per trackkm (ProRail estimate given by e-mail, July 2, 2009). For these costs to be applicable electronic interlockings and the RBC have to be in place. ProRail estimates differ for electronic interlockings between ERTMS and ATB. Costs of electronic interlockings for ERTMS are estimated to be higher, as also RBC and its subsystems are an integral part of the “interlocking” estimate (see also table 3.2). These costs add up to 950 k€ per trackkm, combined with 45 k€ a total of 995 k€ results.

- Line/series specific specifications are used, further reducing possibilities for economies of scale

The factors mentioned have led to the belief that benefits from standardization of technology and creating a single market have not yet been captured. Economies of scale in R&D and production have not yet been captured and specifications for small individual (pilot) projects are relatively costly, compared to large standardized projects. This holds for infrastructure as well as rolling stock.

To illustrate the cost drivers of ERTMS projects UNIFE recently presented a breakdown of cost components for trainborn equipment, which is shown in figure 3.1.

Figure 3.1: Cost components for ERTMS trainborn equipment



Source: UNIFE

According to UNIFE, for trainborn equipment the actual costs for standard hardware and software are relatively small, compared to total costs of implementation. In many cases the integration with existing signalling systems and rolling stock as well as getting the actual implementation approved by the authorities are more costly than the actual ERTMS systems. Cost drivers are[77]:

- Whether retrofitting is necessary. Implementing ERTMS in existing rolling stock is more expensive than integrating ERTMS in new rolling stock
- The technical complexity of the project
- The number of units of rolling stock involved
- The number of legacy systems that need to be integrated
- The number of countries (NSAs)

In complex projects where multiple systems need to be integrated and approval is needed in different countries, cost for approval and integration can add up to 90% of ERTMS project costs, leaving ca. 10% for the actual ERTMS equipment. In less complex situations absolute per unit costs are much lower, especially when large series are involved in a single country. In such cases the share of approval and integration costs in total costs can be as low as 10%, leaving 90% for actual systems.

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77 UNIFE, (2009). *Compendium on ERMTS*.

The general perception of both suppliers, infrastructure managers and train operators is that prices could and should go down in the future[78]. This perception is fed by the fact that both technology and markets are developing. Demand will grow strongly the coming years and will probably continue to do so the coming years. On the supply side ERTMS has the possibility to make the European market for signalling systems a level playing field. For this to become reality further developments are needed. Both developments will probably lead to (significantly) lower prices in the future.

3.2 Cost calculations for the different strategies

In this section cost for the different strategies are presented.

3.2.1 Infrastructure costs

A comparison of the unit cost for the investments in the infrastructure in Arcadis and recent observations by ProRail is presented in table 3.5.

Table 3.5: Additional costs of ERTMS compared to ATB B-relay and ATB (k€/trackkm)

	Arcadis	ProRail
Additional costs ERTMS L2 only compared to ATB (B-relay)	?	305[79]
Additional costs ERTMS L2 only compared to ATB (EIXL)	202	20[80]
Additional costs ERTMS L2 dual signalling compared to ATB (B-relay)	?	420[81]
Additional costs ERTMS L2 dual signalling compared to ATB (EIXL)	254	135[82]

Source: ProRail (2009), Arcadis (2007).

Using the ProRail estimates from the business case, the infrastructure costs in the different strategies add up to the figures in table 3.6. In this table the null alternative has B-relay technology in replacement programmes, null+ has electronic interlockings and the associated costs. Table 3.6 represents Net Present Values for all costs occurring in the period 2010-2060, discounted by 5,5%.

[78] On the other hand UNIFE/UNISIG announced in 2005 officially that prices where expected to remain stable as a result of management of additional features required by customers and the fight against obsolescence for the IT-based technology. AEIF (2005/4), impact assessment of the CSS TSI.

[79] See table 3.4: 880k€ for ERTMS L2 only, minus 575k€ for ATB/B-relay.

[80] See table 3.4: 880k€ for ERTMS L2 only, minus 860k€ for ATB/E-IXL.

[81] See table 3.4: 995k€ for ERTMS L2 overlay, minus 575k€ for ATB/B-relay.

[82] See table 3.4: 995k€ for ERTMS L2 overlay, minus 860k€ for ATB/E-IXL.

Table 3.6: Investment costs of replacing 75% of the networks signalling systems (NPV, mio Euro)

	Null alternative	Null+ alternative	Sector strategy	Natural replacements	Upgrading
Total (null alternative)	-€ 1,173		-€ 1,859	-€ 1,529	-€ 1,986
Compared to Null			-€ 686	-€ 356	-€ 813
Total (null+ alternative)		-€ 1,719	-€ 2,085	-€ 1,840	-€ 2,189
Compared to Null+			-€ 366	-€ 121	-€ 470

The implementation of ERTMS costs momentarily more than just renewing the current ATB system. The major cost component is the more expensive electronic interlocking needed for the ERTMS L2 implementation. Compared to a situation where electronic interlockings are also used in combination with ATB (as in the null+ alternative), the additional costs of ERTMS are much lower.

As ERTMS implementation is more expensive than just renewing the ATB system, the alternatives with the highest ERTMS implementation tempo have the highest costs expressed in NPV. However, the bandwidth is quite large. Under the current assumptions the sector and upgrading strategy are more expensive than the natural replacement strategy. The assumptions that the implementation period is 23 years in these two strategies and an ATB only system without upgrade possibilities to ERTMS is installed until all rolling stock is converted, are playing a major role in the costs. These assumptions cause that a part of the network is renewed in the period till 2020 using an ATB only system and will again be replaced by ERTMS within 20 to 25 years, while the technical lifetime of the ATB system is 40 to 50 years. Adjusting these assumptions will lead to significantly different outcomes. In that case the natural replacement strategy can become more expensive than the other implementation strategies, as dual signalling is needed in this strategy. This is shown in the sensitivity analysis in chapter 5.

3.2.2 Investments in rolling stock

Besides implementation of ERTMS in the track, also trains need to be fitted with ERTMS. Existing trains can be retrofitted with ERTMS and ATB STM, new trains can be equipped with ERTMS and ATB, or once there is enough ERTMS infrastructure, ERTMS only.

Operators have some experience from the past few years with implementing ERTMS in their rolling stock. The costs for the first twenty trains of freight operators on the 'Betuwelijn' were almost € 500,000 per retrofitted train for ERTMS L2 implementation and almost another € 150,000 per train to make them compatible with ERTMS L1[83]. In Switzerland the costs for retrofitting ERTMS trains

[83] Interview KNV. Note: this is a typical problem of a product in its developing phase. ERTMS L2 should be backwards compatible with ERTMS L1, so an ERTMS L1 compatiblity ugrade shouldn't be necessary when a train is already equipped with ERTMS L2. However differences and developments in ERTMS versions made this upgrade necessary.

were around € 400,000 per train, for over 500 trains. ERTMS in new trains cost around € 360,000, but prices are likely to go down to € 165,000[84].

At the time of writing costs are estimated to be lower. Arcadis estimated the costs of the conversion of a train to ERTMS L2 at € 240,000. Costs of implementing ERTMS in a new train are estimated at € 125,000. The total costs of upgrading the rolling stock fleet from ERTMS L2 version 2.3.0.d to L2 baseline 3 are estimated at € 50 million[85]. NS expects the costs of ERTMS in rolling stock to go down, as operators are bundling their power to demand lower prices[86].

Costs are based on an average per train. For small fleets of train types, like the ICE or some types of cargo trains, costs will be much higher per train (see also section 3.1.2) [87]. The certification and development costs to make ERMTS work in a certain train type, are a large part of the total implementation costs for rolling stock. Soft- and hardware has to cooperate with the specific systems in the train. Therefore the costs per train are higher for ICE trains, than for the popular double deck intercity trains (DD-VIRM).

There are 1450 trains in the Netherlands, consisting of over 1750 units needing signalling equipment[88]. 100 units and 100 trains are already equipped with ERTMS, according to Arcadis. This leaves 1350 trains and 1650 units to be converted if the whole fleet needs to be fitted. Trains have a life cycle of around 40 years[89]. NS uses a technical lifecycle of 30 years in its calculations. Some trains will be operational for a longer time, other trains are phased out after a shorter period. In this analysis a lifecycle of 40 years is used, meaning that each year 2.5 percent of the trains will be replaced by new ones.

As an increase of 20% of passenger transport is expected in 2020, the number of passenger trains will also increase by 20% (in each scenario). As rail cargo is expected to grow significantly (see section 2.1.2) a significant increase in cargo trains is also assumed. Cargo trains will be fitted with ERTMS in each scenario as they use international corridors. As it is necessary to have all trains converted in the sector and upgrading strategy, the tempo of equipping trains with ERTMS will be higher than in the null alternative and the natural replacement alternative. Passenger trains (apart from high speed Fyra and Thalys trains) will not be fitted with ERTMS in the null alternative.

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84 Bundesamt für Verkehr BAV (2008), *European Train Control System ETCS*, Standbericht Nr. 2008

85 Arcadis (2007). *Second opnion ERTMS implementatieplan en 160 km/u.*

86 Interview NS

87 According to NS for the DB/NS fleet of 17 ICE, total retrofit costs are estimated around € 9,2 mln, equalling 540k per ICE train.

88 Spoorbranche/ProRail (2009), Materieeloverzicht, standdatum 11-12-2009. Arcadis also uses 1750 units.

89 Arcadis (2007), *Second opnion ERTMS implementatieplan en 160 km/u*

Table 3.7: Costs of investments in rolling stock compared to null alternative (based on Arcadis) (NPV, mio Euro)

	Null alternative	Null+ alternative	Sector strategy	Natural replacements	Upgrading
Total	-	-	-€ 433	-€ 250	-€ 466

In the null alternative there are of course costs for rolling stock replacements. But they are not presented in the table as not all costs of replacing and purchasing new rolling stock are relevant for this study (we also do not present the costs of replacing railway tracks and building new train stations). Therefore only the costs of measures needed in rolling stock to implement ERTMS in the Dutch railway system, are presented.

The sector and upgrading alternatives do not differ much in implementation costs, even though implementation starts three years earlier in the upgrading strategy and cost for upgrading rolling stock are made. However, as it is assumed that the number of travellers by train, and the number of trains alike, will grow until 2020. As in the sector strategy ERTMS is only implemented from 2015, the number of retrofitted trains is larger than in the upgrading strategy where implementation starts in 2012. In the upgrading strategy trains purchased in the 2012–2015 period will directly be equipped with ERTMS. In the sector strategy they will be retrofitted from 2015 onwards, which is more expensive.

In the natural replacement strategy the number of rolling stock retrofitted with ERTMS is the smallest of the three implementation strategies. Only half of the trains has to be retrofitted. However a segregation within the fleet of passenger trains is needed in this strategy: one part used on ERTMS corridors and another part for the rest of the network in the period when not all rolling stock has yet been converted. This causes that the utilization of rolling stock becomes less efficient. In the 2006 sectors strategy it was estimated that this caused an efficiency loss of five percent, resulting in additional costs of € 280 mio to be invested in additional rolling stock[90]. Arcadis valued these losses at € 100 mio (ca. €85 mil in NPV). The results shown in table 3.7. are based on this number of € 100 mio.

Something that is not taken into account is the fact that trains will probably be converted by train type and not by location where a train is going to drive, as almost all train types are used on the complete network. When the rolling stock fleet is segregated into a part for ERTMS corridors and a part for the rest of the network, the geographical use of train types will play a role. This will influence the actual spread of periodic costs of ERTMS implementation in rolling stock and might have additional consequences for the operational costs and feasibility of the natural implementation strategy.

[90] ProRail (2006). *Implementatiestrategie ERTMS.*

3.2.3 Maintenance costs

The maintenance costs consist of two components: maintenance of interlockings and maintenance of ‘outside components’ like signals, balises, cable, switch control boxes and train detection. Maintenance of the outside components is expected to be cheaper for ERTMS than for ATB. Differences are however expected to be smaller than in surrounding European countries. This is due to the fact that electric mechanical relays are already replaced by durable and energy efficient electronic relays[91] and conventional signals are replaced by LED-signals, needing much less maintenance. Per kilometre the maintenance costs of outside components are expected by ProRail to be as follows:

- ATB: ca. € 4,200.- per kilometre
- ERTMS: ca. € 3,500.- per kilometre

Box: Benefits of replacing the GRS train detection system by axle counters

Maintenance of the GRS system on worn ‘electric track insulation welds’ costs yearly several millions of Euro’s. Based on the maintenance costs in Denmark, unit costs can add up to approximately € 1,500.- per km track, corrected for a more intensively used network in the Netherlands.

Failing electric track insulation welds, needed in the track circuit for GRS train detection, are causing yearly 1,200 out of 7,700 interruptions in the time schedule for which ProRail is responsible (a TAO) and therefore need quite a lot of maintenance. Approximately 10 percent of all delays is caused by third parties, especially near level crossings, which corresponds to approximately 3,000 TAO’s. So 1,200 TAO’s are assumed to be responsible for 4 percent of all delays. The preclusion of these failures will reduce the delays by 4 percent. With average delays of 1.2 minutes, average travel times for all passenger can be reduced by 3 seconds.

With ERTMS it is possible to use axle counters instead of GRS track circuits for train detection. This way maintenance costs can be reduced and delays can be prevented. However, as replacing the GRS train detection by axle counters does not necessarily result from ERTMS implementation and additional costs have to be made, this is not included in this analysis. We can calculate the benefits from this measure, but the costs are unknown.

For maintenance of the interlocking part, ERTMS is expected to be much more expensive than the conventional ATB B-relay system. In the initial implementation strategy of the sector this was left out of consideration as costs were compared to a situation where all conventional interlockings were already replaced by modern ones. Due to the complexity of the system, electronic interlockings are more expensive to maintain. Only specialists of the supplier of the electronic interlockings are able to maintain the system, causing the creation of monopolies for maintenance. The only party that can maintain the interlockings is the supplier who initially installed the system. For the conventional ATB B-relay system there are more parties capable of maintaining the system.

The maintenance costs of the Amsterdam – Utrecht line increased from € 100K to around € 1 mio per year since electronic interlockings and ERTMS L2 overlay was implemented. This included a

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[91] ProRail (2009). *Beheerplan 2010.*

doubling of tracks, but costs would not have exceeded € 200K with ATB[92]. Maintenance costs for the first three corridors with electronic interlockings in Mistral, are estimated at €2.53 mio per year[93]. However, a major cost increasing factor, is the fact that a complete maintenance organization has to be set up and be available 24 hours a day, for just a couple of kilometres of track. According to Bombardier and Alstom the costs of additional track maintenance would be around the current cost level of ATB maintenance. The industry is also looking for possibilities to let other organizations take care of trackside maintenance, but responsibility for the system is an issue. Also ProRail expects that as modern interlockings are implemented on larger scale, fixed costs for maintenance will be spread and the maintenance costs per kilometre will decrease. However the decline expected by ProRail is smaller than the industry mentioned[94]. ProRail estimated the costs as follows[95]:

- B-relay interlockings with ATB: € 1,500 per kilometre
- Electronic interlockings with ATB: € 5,300 per kilometre on average: € 7 – 10 K per kilometre in the first few years, stabilizing around € 4,700 per kilometre.
- Electronic interlockings with ERTMS: € 6,300 per kilometre on average: € 8-15 K per kilometre in the first few years, stabilizing around € 5,500 per kilometre.

Table 3.8: Maintenance costs used in SCBA in € per track km

	Outside elements	Other maintenance costs	Total maintenance costs
ATB B-relay	€ 4,200	€ 1,500	€ 5,700
ATB E-IXL	€ 4,200	€ 5,300	€ 9,500
ERTMS	€ 3,500	€ 6,300	€ 9,800

Source: ProRail business case, edited by Decisio

Table 3.9: Total maintenance costs in period 2010 – 2050 (NPV, mio Euro)

	Null alternative	Null+ alternative	Sector strategy	Natural replacements	Upgrading
Total (null alternative)	-€ 536		-€ 630	-€ 591	-€ 648
Compared to Null			-€ 94	-€ 55	-€ 112
Total (null+ alternative)		-€ 660	-€ 680	-€ 662	-€ 687
Compared to Null+			-€ 19	-€ 2	-€ 27

As maintenance of ERTMS infrastructure is more expensive than maintenance of ATB B-relay systems, the strategy starting the earliest with large scale ERTMS implementation is the most expensive one. The total costs in the null+ alternative are larger because maintenance of electronic ATB interlockings is more expensive than of B-relay interlockings. The project alternatives are also more expensive in absolute costs, as in the period before ERTMS is implemented, ATB relay technology is

92 Interview ProRail, june 10th 2009

93 ProRail (2009). *Beheerplan 2010*.

94 Interviews Bombardier, Alstom and Siemens

95 ProRail (2009), *Financiële analyse, Bijlage 1 bij Business Case Mistral Integrale Vervanging & ERTMS*.

replaced by electronic technology just as in the null+ alternative. Compared to the null+ alternative, the project alternatives are less expensive.

3.2.4 Reduction of infrastructure capacity investments

The original sector strategy mentioned savings on physical infrastructural investments (not signalling installations but additional double/quadruple tracks, fly overs etc.). If there is a lack of infrastructural capacity to meet future demand, additional physical capacity is needed to be able to supply the services that existing and new passengers demand. With ERTMS however, operational rules can be optimised, thereby augmenting capacity on existing infrastructure. That these possibilities can be substantial in solving bottlenecks, is shown by the examples given in appendix G.

A detailed analysis of specific bottle-necks on the Dutch railway network has not been carried out yet, making it difficult to estimate the real possibilities of ERTMS in reducing investments in physical capacity. Also the PHS interaction is of importance. PHS is intended to solve all capacity problems in the near future by physical investments, making additional "ERTMS capacity gains", superfluous. So, once PHS has been carried out, (further) capacity gains of ERTMS will have no use.

In the strategies observed in this SCBA, this means that the sectors strategy cannot have these benefits as it only starts investing in the ERTMS equipment in the infrastructure in 2020, the year the PHS programme will have been completed. Something similar holds for the Natural Replacements strategy. In order to be able to have all benefits from optimised operations, especially on busy track sections, it is imperative that every train passing is equipped with ERTMS. Since this is not possible before a very substantial part of the fleet of rolling stock is equipped with ERTMS, these benefits are also not possible in the Natural Replacements strategy. Only starting early will make large savings on planned physical infrastructure projects possible. This is the case in the "Upgrading" strategy.

Table 3.10: Possible reductions of investments in physical infrastcructure (NPV, mio Euro)

	Null alternative	Sector strategy	Natural replacements	Upgrading
Reduction capacity investments	€ 0	€ 0	€ 0	+PM

3.2.5 Training costs

The sector estimated in their ERTMS implementation strategy a reduction of € 2 mio a year in training costs, as a result that train drivers need to use just one system with onboard signalling. However all current personnel has to be retrained to be able to use ERTMS. And as long as not the complete network is equipped with ERTMS, they have to be able to use at least two different systems (international train drivers even more). This results in higher costs which are not estimated by the sector.

An interview with the NS resulted in the conclusion that benefits of lower training costs are insignificant[96]. An net increase in costs is expected because current employees have to be retrained, but an estimation could not be given. Compared to the total costs of the ERTMS implementation these costs are seen as insignificant by the sector.

Table 3.11: Possible effects of personnel training costs (NPV, mio Euro)

	Null alternative	Sector strategy	Natural replace-ments	Upgrading
Training costs	€ 0	+/-PM	+/-PM	+/-PM

3.2.6 Overview of total costs

In this paragraph an overview of the costs discussed above is presented. First we present the costs used in this study for the sector strategy next to costs calculated in earlier studies. Table 3.12 is the same as table 3.1, presenting estimates of nominal costs for the sector strategy, with an added column with the figures used in this study. For the infrastructural investments a bandwidth is given: the higher figure represents the costs compared to the null alternative, the lower figure represents the costs compared to the null+ alternative.

96 Interview NS

Table 3.12: Overview of different estimates of nominal costs of the sectors strategy

	Sector implementation strategy 2006	**BAH audit strategy 2007**	**Arcadis 2nd opinion 2007**	**This study**
Retrofit rolling stock	280 mio	336 mio	353 mio	370 mio[97]
ERTMS implementation new rolling stock	-	-	22 mio	59 mio[98]
Upgrade baseline 3	-	-	50 mio	-
Leasing extra rolling stock	-	-	30 mio	-
Subtotal rolling stock	**280 mio**	**336 mio**	**455 mio**	**429 mio**
Savings on infrastructure	-170 mio	-1,000 mio	-	-
Implementing ERTMS L2 in complete network	600 mio	600 mio	1313 mio	130 - 1983 mio
Conversion signalling installations ('08-'13)/('10-'20)	-	-	180 mio	140 - 1,047 mio[99]
Investments in GSMR needed	-	50 mio	-	-
Subtotal infrastructure	**430 mio**	**-350 mio**	**1,493 mio**	**270 – 2,683 mio**
Total	**710 mio**	**-14 mio**	**1948 mio**	**699 – 3,112 mio**

Table 3.12 shows that the lower values in the bandwidth calculated are somewhere between the values that were calculated earlier. The higher calculations are much higher than values calculated before. The main reason for this difference is the (assumed) impossibility to integrate existing signalling systems with ERTMS. These values for the sector strategy are compared to the calculated values for the other strategies in table 3.13.

97 Costs per train are equal to Arcadis numbers, but expected growth of the fleet is included in results

98 Costs per train are equal to Arcadis numbers, but expected growth of the fleet is included in results

99 Note: both the lower and the higher value present possible costs for electronic interlockings, and are thus applicable to the comparison with the null+ alternative. Conversion costs in case of a B-relay system are estimated at € 700 mln.

Table 3.13: Overview of nominal costs of the different strategies in this SCBA

	Sectors strategy	Natural Replacements	Upgrading
Retrofit rolling stock	370 mio	86 mio	346 mio
ERTMS implementation new rolling stock	59 mio	205 mio	70 mio
Upgrade baseline 3	-	17 mio[100]	50 mio
Segregated fleet		106 mio	-
Leasing extra rolling stock	-	-	-
Subtotal rolling stock	**429 mio**	**414 mio**	**466 mio**
Savings on infrastructure	-	-	-
Implementing ERTMS L2 in complete network	130 - 1983 mio	249 - 1157 mio	130 - 1983 mio
Conversion signalling installations ('08-'13)/('10-'20)	140 - 1,047 mio	0	115 - 734 mio
Investments in GSMR needed	-	-	-
Subtotal infrastructure	**270 – 2,683 mio**	**249 – 1157 mio**	**245 – 2473 mio**
Total	**699 – 3,112 mio**	**663 – 1571 mio**	**711 – 2939 mio**

Table 3.13 shows that nominal costs for investments in rolling stock do not differ very much. This is mainly due to the fact that in all strategies, including Natural Replacements a significant part of all rolling stock is converted (in this table 50% by 2020 is assumed in the Natural Replacements strategy.

Costs for the infrastructure do differ in the different strategies. The natural replacement strategy has the highest nominal costs if additional costs are relatively low (meaning electronic interlockings are implemented in the null(+) alternative). This is due to the fact that more expensive dual signalling is implemented in part of the network. These additional costs however are far outweighed if implementation costs itself are high (meaning B-relay interlockings are implemented in the null(+) alternative).

Table 3.14 shows the discounted values (NPV) for the different strategies compared to the null alternative. Table 3.15 shows these values compared to the null+ alternative

100 Costs per train are equal to costs in upgrading strategy (probably an underestimation of the upgrading costs)

Table 3.14: NPV compared to null

		Compared to null alternative		
	Null alternative	**Sector strategy**	**Natural replace-ments**	**Upgrading**
Costs				
Investments infrastructure	-€ 1.173	-€ 686	-€ 356	-€ 813
Investments rolling stock	€ 0	-€ 433	-€ 250	-€ 466
Maintenance infrastructure	-€ 536	-€ 94	-€ 55	-€ 112
Reduction capacity investments	€ 0	€ 0	€ 0	+PM
Training costs	€ 0	+/-PM	+/-PM	+/-PM
Total Costs	-€ 1.709	-€ 1.213+/-PM	-€ 661+/-PM	-€ 1.391+/-PM

Table 3.15: NPV compared to null+

		Compared to null+ alternative		
	Null+ alternative	**Sector strategy**	**Natural replace-ments**	**Upgrading**
Costs				
Investments infrastructure	-€ 1.719	-€ 366	-€ 121	-€ 470
Investments rolling stock	€ 0	-€ 433	-€ 250	-€ 466
Maintenance infrastructure	-€ 660	-€ 19	-€ 2	-€ 27
Reduction capacity investments	€ 0	€ 0	€ 0	+PM
Training costs	€ 0	+/-PM	+/-PM	+/-PM
Total Costs	-€ 2.379	-€ 818+/-PM	-€ 374+/-PM	-€ 963+/-PM

4 Effects on railway system performance

ERTMS has potential benefits compared to conventional signalling systems in Europe. The UIC Compendium on ERTMS mentions interoperability, safety and capacity as main potential benefits from ERTMS[101]. In July 2007 the sector described performance effects resulting in shorter travel time and shorter headways[102]. We will discuss the effects on interoperability, travel time and capacity as direct benefits of ERTMS. We end this chapter with a description of the external and indirect effects.

101 UIC (2009), *Compendium on ERTMS*

102 Ministerie van Verkeer en Waterstaat (2008). *Voortgang ERTMS en onderzoek ingebruikname Amsterdam-Utrecht*, Brief: 11 juli 2008, VenW/DGP-2008/5196, Bijlage 4, Beantwoording van de vragen over de ERTMS implementatiestrategie van de spoorsector

Table 4.1: Possibilities of different signalling configurations

	ATB	ERTMS L2 only	ERTMS L2 overlay/dual signalling	ERTMS L1 only	ERTMS L1 overlay
160 km/h	Possible with adjustments	Possible	Only possible for converted trains in a mixed fleet	Possible	Same remarks as L2 overlay.
Smaller discrete speed steps	Not possible.	Possible	Only possible for converted trains in a mixed fleet	Possible	Same remarks as L2 overlay.
Postponed braking	Not possible	Possible	Only possible for converted trains in a mixed fleet	Possible	Same remarks as L2 overlay.
Driving advice	Possible with limitations, adjustments like 'routelint' needed	Possible as an integrated system with continuous data	Possible with limitations, depending on the mix of the fleet	Equal to ATB	Equal to ATB
Shorter headway	Limited, some optimizations are possible, but not as much as with ERTMS.	Possible, can increase capacity near junctions	Possible with limitations, depending on the mix of the fleet	Less efficient than L2, as point to point communication is used. Not (significantly) different from ATB	Not (significantly) differtent from ATB.
Disconnecting movement authority from speed protection	Already the case	Equal to ATB, but by cab signalling instead of signals	Equal to ATB, but by cab signalling instead of signals	Equal to ATB	Equal to ATB
Block optimization	Limited by number of signals, regulation for visibility in curves, switches and level crossings	No limitation	Using signals the same limitations as ATB apply	With signals the same limitations as with ATB apply. Using infill loops, block lengths can be optimized	Equal to ATB

4.1 Interoperability

4.1.1 Introduction

This effect applies only to international rail traffic, mainly freight traffic. The effect consists of different elements:

- Investment costs in rolling stock: Only one system has to be implemented in rolling stock when the international network is equipped with ERTMS. Today trains crossing multiple borders need to have multiple systems on board.

- Reduction in travel time: Cargo trains are expensive to be equipped with ATB and the French KVB system[103]. This causes that traction units have to be switched at the Belgium or French border. This causes an increase of the travel time by at least half an hour. Implementation of ERTMS means that the same amount of freight can be transported by less traction units in shorter time.
- Capacity: because trains have to switch traction units at the border, a lack of capacity exists at the border.
- Competition: it is easier for a foreign operator to enter the market when systems are interoperable. This can reduce costs of rail traffic and make the market more efficient.

For international operability, international agreements have to be made. As these have only been developed for the corridors Rotterdam – Genoa and the HSL-zuid, these are the only corridors profiting from ERTMS. However, ERTMS on these corridors is implemented in all alternatives, so there is no difference between the null alternative and the other alternatives[104].

Travel time of cargo trains can be reduced by 30 minutes on each border. Passenger trains, like the Thalys, can reduce the costs of their rolling stock as the train has to deal with only one safety system. But as just two international corridors have been agreed upon, and these are also fitted with ERTMS in the null alternative, no differences between the null alternative and the other alternatives are to be expected.

Note: interoperability effects are dependent on investments in other European countries. As long as these investments are not taking place, benefits of interoperability are small. When investments in other countries takes place, there is a risk that other types of ERTMS software are used in the track, which can cause extra investments in rolling stock. Benefits for diesels are earlier visible than benefits for electrical trains, as the voltage differs in Europe. One single market for all types of rail traffic is therefore not expected soon, but increased competition is expected on international corridors like Rotterdam - Genoa.

4.1.2 Interoperability in the different strategies

The most important international corridors (Betuweroute, HSL Zuid) are already fully equipped with ERTMS or will be in the near future. This means that also in the null alternative most benefits from interoperability will be captured.

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[103] Technically it is possible, but KNV mentioned that combining the French and Dutch system in one train is quite complex and expensive. Therefore trains are seldom equipped with as well the Dutch, Belgian and French system.

[104] This is a simplification: with a complete ERTMS network in the Netherlands, foreign operators can distribute their goods over the whole network, instead of just to Rotterdam. This effect is not taken into account.

For additional benefits on other corridors, new international connections that are also equipped with ERTMS abroad will have to come into service. These effects depend on neighbouring countries and are not taken into account.

There is one other benefit from interoperability that is not dependant on other countries. This effect will take place in the very long term, when the complete Dutch network is equipped with ERTMS. Then it is possible for newly built international trains not to have a ATB-system on board, which can save some costs. These costs are however, especially as they take place in the long term and count only for newly built trains, insignificant. We therefore do not allocate any benefits of Dutch ERTMS implementation to interoperability.

4.2 Speed and travel time

4.2.1 Introduction

On a couple of routes the infrastructure is capable of allowing speeds up to 160 km/h instead of the current maximum of 140 km/h[105]. The routes where an increase of the maximum speed is possible are:

- The "Hanzelijn" (Lelystad – Zwolle) (200 km/h is theoretically possible, but for the moment the maximum speed is limited to 160 km/h[106]. As a dual signalling system is currently being implemented, no extra investments in ERTMS infrastructure are needed);
- Leiden - Den Haag;
- Amsterdam – Utrecht;
- Boxtel – Eindhoven;
- Almere – Lelystad.

ATB and 160 km/h

With some modifications to the ATB system, it is possible to increase the maximum speed to 160 km/h. It is estimated that an investment of € 50 mio is needed to make this possible. However an agreement could not be reached to make these investments and European legislation might prevent it, as further optimization of national systems is not allowed anymore. The gains of higher speeds can therefore be interpreted in two ways: the actual gains in travel time or saving on an investment of € 50 mio In this analysis the benefits from a reduction of travel time are presented.

On all other lines the infrastructure itself (curves, switches, weak foundations, level crossings etc.) is the bottleneck in the maximum speed and not the signalling system. Also the fact that slow and fast trains drive on the same track is a bottleneck. A higher speed means that the fast train will be slowed down by the slow train earlier. We therefore assume that the benefits of 160 km/h only take place on these mentioned corridors. Besides that, the ATB system is capable of speeds till 160 km/h, but it is not used at the moment as there is no agreement to do this. For speeds above 160 km/h ERTMS is a necessity as cabin signalling is needed (theoretically speeds up to 500 km/h are

[105] There are plans to run trains at 160 km/h on existing infrastructure (without needing ERTMS). As the realisation of these plans is uncertain, we assume speeds of 160 km/h are only possible with ERTMS.

[106] Existing rolling stock isn't able to run 200 km/h and there are no agreements made for purchasing rolling stock capable of driving these speeds.

possible), but an increase in speed above 160 km/h is not foreseen in the Netherlands. For speeds over 160km/h higher voltage overhead wiring is needed on almost all track sections.

A maximum speed of 160 km/h results in the following travel time reductions[107]:

- The “Hanzelijn” (Lelystad – Zwolle), 1 minute travel time reduction;
- Leiden - Den Haag, 15 seconds of travel time reduction;
- Amsterdam – Utrecht, 1 minute of travel time reduction;
- Boxtel – Eindhoven, 1 minute of travel time reduction;
- Almere – Lelystad, 1 minute of travel time reduction.

High speed is not the only possibility for travel time reductions. Travel time can also be reduced by other means:

- Delayed braking: instead being forced to brake when passing a yellow signal, the train driver is forced to brake before reaching the red signal. This can be adjusted to the characteristics of each specific train. A light train is then allowed to brake later than a heavy cargo train. With ATB each train has to brake as if it is the train with the longest braking distance.
- Following cargo trains at higher average speed: when a cargo train is in front of a faster train, the fast train following the cargo train will see, with ATB, a yellow light and is forced to brake to 40 km/h. With ERTMS L2, the fast train can drive a higher speed provided a safe braking distance to the section occupied by the cargo train is remained.
- Smaller discrete speed steps: ERTMS uses steps of 5 km/h instead of steps of 20 km/h or larger. In a case where it is unsafe to drive 60 km/h, but a speed of 50 km/h is not a problem, the speed is limited to 40 km/h with ATB. With ERTMS it is possible to drive 50 km/h, which is a gain of 25% in speed.
- With more options for block optimization with ERTMS L2, trains can enter and leave an station area quicker. They can be instructed to stop closer behind a train on the platform and visibility of signals on complex junctions with a lot of track switches, does not play a role anymore. This enables train drivers to enter the station areas more smoothly and possibly at higher speeds.

All above effects will gain some seconds in travel time. For freight trains these optimizations can make the difference from fitting in the time schedule, or being delayed for sometimes long periods. In the SCBA analysis it is assumed that on every corridor between two medium-large to large junctions the above effects will count up to an average reduction of travel time by half a minute. This is assumed for passengers as well as freight trains[108].

An additional effect of shorter travel times is that it attracts new passengers. If travel times by train are improved, the number of times that public transport is the faster mode of transport will increase,

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[107] Verkeer en Waterstaat (2007) *Landelijke Markt- en Capaciteitsanalyse Spoor.*

[108] This is in line with ProRail (2006), *Implementatiestrategie ERTMS*. See also box on page 15.

causing a *modal shift*. The attraction of additional passengers is also taken into account in the analysis.

4.2.2 Speed and travel time in the different strategies

Travel time reductions as described in the previous section add up to different totals for the different strategies. Table 4.2 presents yearly travel time savings in the different strategies in mio hours, compared to the null(+) alternative. As number of ERTMS corridors and the number of passengers grow over the years, so does the total of travel time reductions.

Table 4.2: Travel time savings due to 160 km/h and delayed braking, in mio hours/year

	2010	2015	2020	2025	2030	2035	2040	2045
Sector strategy	0,0	0,0	1,6	3,3	6,8	8,2	9,6	10,4
Natural replacements	0,0	0,1	2,3	2,3	2,3	4,4	5,5	6,6
Upgrading	0,0	0,0	2,6	3,3	7,7	9,1	10,4	10,4

In table 4.3 the yearly travel time savings are valued with the appropriate values of time. Figures in the table represent nominal values in prices of 2009.

Table 4.3: Nominal benefits of travel time savings, in mio € / year

	2010	2015	2020	2025	2030	2035	2040	2045
Sector strategy	0	0	13	29	64	82	101	110
Natural replacements	0	1	19	21	22	44	58	70
Upgrading	0	0	22	30	73	91	110	110

The net present value for the above figures is calculated in table 4.4.

Table 4.4: Benefits of travel time reduction for passengers in mio € NPV

	Null (+)	Sector strategy	Natural replacements	Upgrading
Travel time passengers	€ 0	€ 706	€ 418	€ 811

The same analysis is made for freight traffic. The results are shown in table 4.5.

Table 4.5: Benefits of travel time reduction for freight in mio € NPV

	Null (+)	Sector strategy	Natural replacements	Upgrading
Travel time freight	€ 0	€ 43	€ 31	€ 52

For cargo shippers the benefits of ERTMS mentioned in the table are probalay underestimated. ERTMS might make the difference between an hour delay or not, depending on the possibilities to schedule freight trains in the time schedule for passenger trains. However, this needs to be studied by specific location and route. At border crossings there are also some major benefits possible, but these are depending from foreign investments in ERTMS.

4.3 Increase in capacity

4.3.1 Introduction

To collect gains from an increase in capacity, there has to be a lack of capacity. The national market and capacity analysis (LMCA) expects shortages in 2020 on de following routes (provided the HSL-Zuid is functioning and freight traffic is rerouted over the Betuweroute):

- The Hague – Schiphol – Almere - Lelystad
- Alkmaar – Eindhoven
- Utrecht – Arnhem/Nijmegen (minor problems)
- The Hague – Rotterdam
- Utrecht – Rotterdam/The Hague (only freight traffic)

Box: Trade off speed and capacity

A higher speed enables a train to reach its destination earlier. It however does not mean that capacity increases as more trains are able to ride the track in the same time. This is because trains travelling at a higher speed need a larger headway as their braking distance increases. Especially on corridors with trains travelling at different speeds, an increase in maximum speed can actually decrease the capacity on a corridor.

The PHS programme should solve all these capacity issues[109]. So provided the full PHS programme is going to be executed, no capacity shortages are foreseen. However it might be possible that some measures of the PHS programme are not necessary after implementing ERTMS. Another advantage of ERTMS might be an increase in the quality of the time schedule (trains departing every ten minutes instead of a 7/13 or 8/12 minute schedule).

Capacity increases mainly near complex junctions. Because visibility of signals does not play a role, block sections can be optimized. They can end closer to danger points and switches, shortened near stations and placed in curves where signals are not visible[110]. This causes that the headway between two trains can be reduced, which increases capacity. On the non stop track between stations a capacity increase is not expected by implementing ERTMS, as different travel speeds will not make it possible to let trains follow each other closer.

Studies in Europe show a large bandwidth of possible capacity gains with ERTMS: from almost no gain in capacity to over 30 percent. Image 4.1 shows the theoretical capacity gain of ERTMS on a average main line in Europe. However, the Netherlands already have a busy occupied railway network. Block sections are around 1500 meter, where the calculations in image 4.1 are made with block sections of 3 km. This means the capacity increase will fall out lower than shown in this image.

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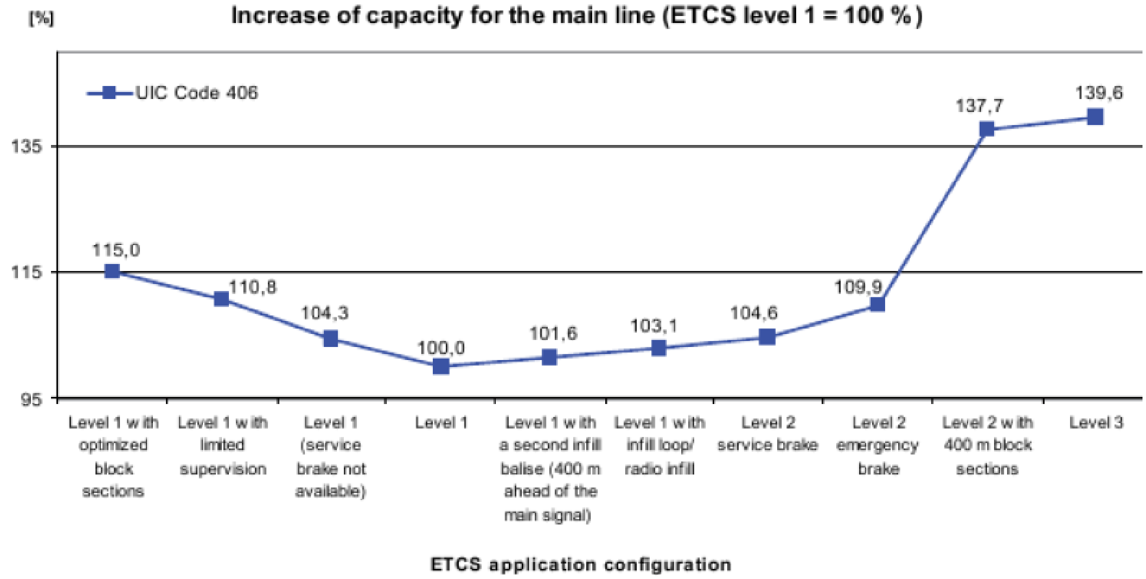
[109] Conversation with PHS civil servants, may 12th

[110] Ministerie van Verkeer en Waterstaat (2008). *Voortgang ERTMS en onderzoek ingebruikname Amsterdam-Utrecht*, Brief: 11 juli 2008, VenW/DGP-2008/5196, Bijlage 4, Beantwoording van de vragen over de ERTMS implementatiestrategie van de spoorsector

Figure 4.1 Capacity with ERTMS versions



Source: Influences of ETCS on line capacity – Generic Study, UIC, 2008.

SYSTRA calculated capacity gains of ERTMS implementation of 6 to 12 percent in France. In the Netherlands this will be lower as the current ATB system is optimized. An overall capacity gain of 3 to 6 percent would therefore be more realistic in the Netherlands. But the overall gain is perhaps not the correct measure. If the most severe bottlenecks can be solved, there might be additional capacity benefits. In theory, proper use of ERTMS and a new set of ERTMS optimized directives for driving (incl optimized block lengths etc.) could reduce the number of bottlenecks in the Netherlands and have large capacity gains.

But if capacity gains can be obtained, what then would be the actual benefits of this additional capacity. As we described in chapter two the expected capacity gains will be solved by the PHS programme, which will be completed before the original strategies (sector strategy and natural replacements) start with investments in the infrastructure. This is however not the case in the Upgrading strategy, which in theory can make PHS investments superfluous. A detailed analysis of the provisional PHS programme and its individual projects and the possible effects of ERTMS on these projects would be needed to assess the impact of ERTMS. This was beyond the scope of this study, but a quick scan of several cases indicates that costs could be reduced significantly. Appendix G shows several examples.

There is however another possible benefit from further capacity augmentations above the PHS level. Time schedules can become more robust as larger capacity and an improved more flexible traffic management system makes easier to deal with delays. There is also the possibility of a further optimization of time schedules. We assume that on every line were 6 intercity trains can depart every hour, this will be possible in a 10/10/10 schedule with ERTMS, instead of a 8/12/8/12 schedule without ERTMS. Appendix A shows how customers will value this optimization of the time schedule.

4.3.2 Capacity translated to the different strategies

The PHS programme has a granted budget of around € 4.5 bil.[111] Of this budget € 1.3 bil. is allocated to the OV-SAAL corridor (Schiphol – Amsterdam – Almere – Lelystad). Half of the remaining € 3 bil. budget is for investments in "integral capacity management". The other half of the remaining € 3 bil. budget is reserved for investments in the track itself, like signals, platforms and tracks for slow trains to be overtaken by fast trains, but also for measures to reduce noise or creating tunnels instead of level crossings. A first test on the corridor Amsterdam - Eindhoven also showed that it is possible with the current ATB technique to drive a 6/6/2 scheme. ERTMS therefore does not necessarily create additional capacity in terms of extra trains which can be used in the calculations. As cost reductions of ERTMS in the PHS programme are going to be very specific, we also cannot monetize them in this analysis. Some examples of possible cost reductions are given in appendix G.

ERTMS, and especially the traffic management layer when completely developed, might smoothen overtakings of slow trains by intercities and the disturbance caused by interruptions in the time schedule. This way ERTMS can improve the quality of the time schedule and make it more robust for external disturbances. We assume in our calculations that with ERTMS it is possible to ride a time schedule where every ten minutes a train departs on the specified corridors in PHS. Without ERTMS it is assumed that trains will depart in a 8/12/8/12 time schedule on these corridors. The gains of this improvement are calculated in equivalent minutes of travel time. The benefits are shown below.

Table 4.6: Benefits of improved time schedule in mio € NPV

	Null(+) alternative	Sector strategy	Natural replacements	Upgrading
Improved time schedule	€ 0	€ 99	€ 73	€ 111

As passengers profit earlier from the improved time schedule in the upgrading strategy, the benefits are larger than in the sectors strategy and in the natural replacements strategy.

4.4 Exploitation

4.4.1 Introduction

Improved rail services might lead to a modal shift on the mobility market. Less road traffic, leading to less congestion, pollution and accidents on the road might follow. Modal shifts might also take place on air and sea traffic. As demand is already met in the null alternative, these effects will not be very

111 NS, ProRail, BRG (2008). *Programma Hoogfrequent Spoorvervoer Verkenning benodigd investeringsvolume.*

large. A further increase in quality can however attract additional motorists. These effects are hard to quantify and monetize in the scope of this study. They will mainly be described qualitatively.

However the relationship between the travel time and the demand for rail passenger transport, is known. The shorter the travel time becomes, the more people will travel by train. This “travel time elasticity” gives the change in passengers in terms of percentage in relation to the change in travel time in terms of percentage. The in-vehicle-time-elasticity for local regional rail transport lies between -0.4 and -0.9, for long distant intercity transport the values reach up to -1.6[112]. This means that for long distances a reduction of 1 percent travel time, will lead to 1.6 percent more travellers by train. In this study an average travel time elasticity is used of -1 for all rail passenger transport.

Assuming a travel time of 20 minutes on the average corridor between two medium-large to large railway stations, the 30 seconds reduction means a reduction of travel time by 2.5%. On most corridors with ERTMS an increase of 2.5% in passenger demand will take place. On corridors where the speed increases, or the time schedule improves as mentioned in paragraph 4.2 and 4.3, the increase in passenger rail transport will be larger.

4.4.2 Exploitation effects of the different strategies

The increase in passengers as a result of the better time schedules and shorter travel time are derived from elasticities. Which part of these new passengers made a switch from another method of transport and which part are completely newly generated travellers is unknown. These passengers are considered to be additional to the null alternative, in which a growth of twenty percent is already included.[113]

These new passengers of course benefit from the reduction of travel time and are included in the numbers in paragraph 4.2. NS also benefits from these generated passengers by means of additional income. In 2008 the profits from passenger transport on the main railway network, the scope of this study, were € 174 mio[114]. When we assume a constant profit margin per passenger, the passenger increase results in the benefits for operators as shown in table 4.7.

Table 4.7: Exploitation benefits of generated passengers in mio € NPV

	Null(+) alternative	Sector strategy	Natural replacements	Upgrading
Exploitation operators passengers	€ 0	€ 42	€ 34	€ 49

[112] KiM (2007), *Marktontwikkelingen in het personenvervoer per spoor 1991 – 2020.*
[113] KiM (2007), *Marktontwikkelingen in het personenvervoer per spoor 1991 – 2020.*
[114] NS (2009), *Jaarverslag 2008.*

The benefits for operators are discounted against the societal discount factor. A commercial company however, uses a higher discount factor as it has a higher risk en therefore needs to have a shorter payback time for investments and values these benefits lower.

4.5 Effects on safety

4.5.1 Introduction

Implementation of ERTMS reduces the number of SPADS compared to the null alternative. Compared to a situation without ATB VV, ERTMS could reduce the numbers of SPADS by around 80 percent.[115] However, as ATB VV will already reduce the number of SPADS by 50 percent in the null alternative, ERTMS will reduce the number of SPADS compared to the null alternative with 60 percent.

Another benefit of ERTMS are temporary speed limitations on newly constructed tracks or tracks in bad condition. It will also be possible to open or close a certain section of the track for traffic with a handheld terminal, improving the safety of track workers. A higher safety level does not only affect passengers and operators, but also people crossing level crossings or living next to a railway track.

4.5.2 Safety effects in the different strategies

As the ministry, ProRail and NS do not register costs of accidents it is not possible to calculate the benefits of a reduction of SPADS[116]. Material damage is unknown. The railway sector is working on a cost benefit analysis on this issue.[117] However there are methods to monetize the value of life or injuries. This way a part of the benefits can be monetized, but as travelling by train is very safe and the number of accidents resulting in heavy injuries are relatively small, this is probably the minor part of the benefits. The costs of SPADS for heavily injured and deceased people will be calculated with statistics from the SWOV and the SPADS reports.

The number of SPADS and accidents is assumed to be evenly divided over all tracks in the network, so can be expressed per kilometre. The current ATB VV programme is assumed to cause a reduction of 50percent of all SPADS (also evenly divided over all tracks). ERTMS will lead to an reduction of an additional 60 percent when the complete network is equipped.

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[115]See Appendix D.

[116] Ministerie van Verkeer en Waterstaat (2009). *Trendanalyse 2008.*

[117] Ministerie van Verkeer en Waterstaat (2008). *brief: aanpak stoptonend sein passages*, 30 september 2008.

Table 4.8: Safety benefits in mio € NPV

	Null+ alternative	Sector strategy	Natural replacements	Upgrading
Reduction deceased and injured passengers and employees	€ 0	€ 5	€ 2	€ 5
Reduction material damage	€ 0	+PM	+PM	+PM
Reduction of consequential damage	€ 0	+PM	+PM	+PM
Track workers safety	€ 0	+PM	+PM	+PM
Temporary speed limits	€ 0	+PM	+PM	+PM

The strategies with the highest amount of ERTMS kilometres are having the highest benefits. The safety benefit for track workers might increase these numbers by 40 to 100 percent, as the sector expected in 2006 that at reduction of 10 tot 25 percent of accidents with track workers should be possible. In the past 10 years 8 track workers got lethally injured and 36 workers severed non-lethal injuries. However, as material and consequential damage (like delays) of accidents are unknown, the largest part of the safety benefits is probably not included.

4.6 Energy consumption

4.6.1 Introduction

The trains of the NS use around 1100 mio kWh yearly[118], resulting in an energy bill of around € 70 to € 90 mio yearly. Each percentage reduction of energy consumption can reduce the energy bill by almost a million Euro.

A lower energy consumption, will not only cause lower direct costs for operators, but also reduces pollution. The acceleration of a train is responsible for most of the energy consumption on a trip. Maintaining speed costs relatively little energy as the friction from steel wheels on a steel track is low. This means that each unnecessary braking wastes relatively a lot of energy. Better speed adaptation to trains in front leads to less unnecessary braking and less waste of energy. An unnecessary stop between two destinations increases the energy consumption with 30 percent on average.[119]

ERTMS can improve the possibilities to implement advanced technology to give energy generated by braking back to the network. Nowadays energy from braking can only be used if another train is nearby. If however power stations know that a braking train is nearby (something that might be possible with ERTMS L2), it can shut itself temporarily down and give the energy back to the network. This energy saving technology is not a part of ERTMS and also already in use on several urban transport systems and 25kV lines, but ERTMS might make it easier to use examples of technological energy saving solutions like this.

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118 Website: http://www.senternovem.nl/projectengalerij/Overzicht/Energie_en_Klimaat/NS.asp
119 Sierts, Wiersema, Lindhout (2007). *Economisch spoorverkeer met de integrale groene golf*.

The ERTMS system itself however consumes more energy as it is based on ICT technology needing large server parks, but compared to the savings in transport this effect is expected to be insignificant.

4.6.2 Energy consumption in the different strategies

It is unknown how much energy consumption can be reduced by using ERTMS and some smart additional measures. To show the effect of a energy reduction by ERTMS this analysis presents some calculations with hypothetically energy reductions. The calculations are based on an energy price of 7 cents per kWh and a reduction of 15 percent of the energy consumption.

Table 4.9: Reduction of energy conumption in mio € NPV

	Null+ alternative	Sector strategy	Natural replacements	Upgrading
Energy Reduction	€ 0	€ 84	€ 40	€ 88

The benefits of a reduction of the energy bill are direct benefits for the NS. However, they will be discounted against a higher discount rate as used in this analysis. The risk premium of a commercial investment, where risks are born by one party, is higher than in a case where risks are spread society wide. The NS will probablys use a higher discount rate.

Besides the direct benefits from energy consumption, less energy consumptions mean also less pollution. Each kWh consumed produces 0.413 kg CO_2. At a shadow price of 5.6 cents a kilo this results in the following environmental benefits.

Table 4.10: Reduction of CO_2 emissions in mio € NPV

	Null+ alternative	Sector strategy	Natural replacements	Upgrading
Reduction CO_2	€ 0	€ 24	€ 12	€ 26

If ERTMS and additional smart measures are able to reduce the energy consumption of trains by 15%, over 65 mio kg of CO_2 emission can be avoided each year. But as it is unknown how much energy can be saved by implementing ERTMS and using additional measures made easier by ERTMS, these benefits are purely hypothetical.

4.7 Other external effects

Noise pollution and quality of life

If ERTMS increases capacity and the operators are putting on extra trains, the number of trains passing residential area's is raised. This causes a higher level of noise pollution which decreases the quality of life. Higher speeds can also lead to more noise pollution, however most travel time benefits are a result of a smoother approach of junctions and less unnecessary braking, maybe even lowering noise pollution. As this is a minor effect and capacity is expected to be sufficient in the null alternative, we do not expect any further effects on quality of life and noise pollution.

Table 4.11: Reduction of quality of life in mio € NPV

	Null+ alternative	Sector strategy	Natural replace-ments	Upgrading
Quality of life	€ 0	€ 0	€ 0	€ 0

4.8 Indirect effects

Indirect effects are effects on other markets caused by the project. In this case there are two markets where such effects can be expected.

4.8.1 Labour market

If ERTMS shortens travel time this influences the mobility of people and the area they're looking for jobs. Friction in the labour market can be reduced this way, which leads to a lower level of unemployment. How many unemployment can be decreased by a shorter travel time depends on several factors as location and composition of the labour market. Making more detailed calculations about this effect lies not in the scope of this study.

Table 4.12: Labour market effects

	Null+ alternative	Sector strategy	Natural replacements	Upgrading
Labour market	€ 0	+PM	+PM	+PM

4.8.2 Competitiveness of Dutch ports

A better accessibility of the port of Rotterdam and other Dutch Ports can improve their competitiveness in Europe. The implementation of ERTMS causes that trains do not need the ATB system on-board anymore, which makes the Port of Rotterdam accessible for more trains. However foreign electric trains also need to be able to use the Dutch voltage on the overhead wire. The real increase in accessibility comes when more international corridors are equipped with ERTMS. This however does not differ in the null alternative and the implementation strategies. Therefore accessibility plays a minor role in this analysis on national scale. For an implementation on European scale the accessibility of international transport hubs can play a major role in the effects of ERTMS.

Table 4.13: Competitiveness Dutch ports

	Null+ alternative	Sector strategy	Natural replacements	Upgrading
Dutch ports	€ 0	+PM	+PM	+PM

4.8.3 Increased competition

More international competition can make international transport more efficient and reduce prices. When ERTMS is implemented in more EU countries, even competition on national markets is possible when concessions are granted. However the Dutch market is heavily dependant from the developments of ERTMS in the neighbouring countries. In addition, these advantages will only take effect when the complete network is equipped with ERTMS. If not, foreign competitors still need ATB in their equipment. In that case ERTMS can't be the cause of an increased competition.

Table 4.14: Competition transport sector

	Null+ alternative	Sector strategy	Natural replace-ments	Upgrading
Increased competition	€ 0	+PM	+PM	+PM

5 Overview of cost and benefits

5.1 Overview of cost and benefits

5.1.1 Summarizing tables

In this paragraph the costs and benefits of the different strategies will be shown in summarizing tables. The result of the project alternatives will be compared with the null and null+ alternative. Costs implementation and maintenance of the infrastructure will differ between these two comparisons, all other factors remain equal.

Table 5.1 Overview costs and benefits in NPV mio € compared to the Null alternative

		Compared to null alternative		
	Null alternative	Sector strategy	Natural re-placements	Upgrading
Direct effects				
Costs				
Investments infrastructure	-€ 1.173	-€ 686	-€ 356	-€ 813
Investments rolling stock	€ 0	-€ 433	-€ 250	-€ 466
Maintenance infrastructure	-€ 536	-€ 94	-€ 55	-€ 112
Reduction capacity investments	€ 0	€ 0	€ 0	+PM
Training costs	€ 0	+/-PM	+/-PM	+/-PM
Total Costs	-€ 1.709	-€ 1.213 +/-PM	-€ 661+/-PM	-€ 1.391 +/-PM
Benefits				
Interoperability	€ 0	€ 0	€ 0	€ 0
Travel time passengers	€ 0	€ 654	€ 388	€ 755
Improved time schedule	€ 0	€ 91	€ 68	€ 103
Travel time freight	€ 0	€ 42	€ 31	€ 51
Delays	€ 0	+PM	+PM	+PM
Exploitation operators passengers	€ 0	€ 42	€ 34	€ 49
Total benefits	€ 0	€ 830+PM	€ 521+PM	€ 958 +PM
Balance direct effects	-€ 1.709	-€ 382+/-PM	-€ 140+/-PM	-€ 433 +/-PM
External effects				
Safety	€ 0	€ 5	€ 2	€ 5
Energy Reduction	€ 0	€ 84	€ 40	€ 88
Reduction CO2	€ 0	€ 24	€ 12	€ 26
Quality of life	€ 0	€ 0	€ 0	€ 0
Balance external effects	€ 0	€ 114	€ 54	€ 119
Indirect effects				
Labour market	€ 0	+PM	+PM	+PM
Dutch ports	€ 0	+PM	+PM	+PM
Increased competition	€ 0	+PM	+PM	+PM
Balance indirect effects	€ 0	€ 0+PM	€ 0+PM	€ 0+PM
Balance total	-€ 1.709	-€ 269+/-PM	-€ 86+/-PM	-€ 314+/-PM

The “null alternative” column presents investments in signalling systems in the infrastructure for the null alternative, when B-relay technology is used. All other factors (investments in rolling stock, travel time benefits, etc.) are set to € 0. This doesn't mean that within the null alternative rolling stock won't be replaced and no measures will be taken to improve travel time, capacity etc. They are only not related with the selection for a certain type of safety and signalling system. They also do not differ between the null and null-plus alternative, while investments on the infrastructural side do.

The columns belonging to the different ERTMS implementation strategies are presenting the additional costs and benefits compared to the null alternative. For example: the -€ 813 mio for infrastructural investments in the upgrading strategy are coming on top of the - € 1.173 of the null alternative, making total costs of infrastructural investments in this strategy (in NPV) € 1.986 mio.

In the end all implementation strategies result in a negative balance compared to the null alternative. However the total sum of the strategies differs just over € 200 mio between the strategies, differences in costs and benefits are much larger. This is caused by the fact that the most expensive strategy leads also to the largest benefits.

Table 5.2: Overview costs and benefits in NPV mio € compared to the Null-plus alternative

	Null+ alternative	Compared to null+ alternative Sector strategy	Natural replacements	Upgrading
Direct effects				
Costs				
Investments infrastructure	-€ 1.719	-€ 366	-€ 121	-€ 470
Investments rolling stock	€ 0	-€ 433	-€ 250	-€ 466
Maintenance infrastructure	-€ 660	-€ 19	-€ 2	-€ 27
Reduction capacity investments	€ 0	€ 0	€ 0	+PM
Training costs	€ 0	+/-PM	+/-PM	+/-PM
Total Costs	-€ 2.379	-€ 818	-€ 374	-€ 963
Benefits				
Interoperability	€ 0	€ 0	€ 0	€ 0
Travel time passengers	€ 0	€ 654	€ 388	€ 755
Improved time schedule	€ 0	€ 91	€ 68	€ 103
Travel time freight	€ 0	€ 42	€ 31	€ 51
Delays	€ 0	+PM	+PM	+PM
Exploitation operators passengers	€ 0	€ 42	€ 34	€ 49
Total benefits	€ 0	€ 830 +PM	€ 521 +PM	€ 958 +PM
Balance direct effects	-€ 2.379	€ 12 +/-PM	€ 147 +/-PM	-€ 4 +/-PM
External effects				
Safety	€ 0	€ 5	€ 2	€ 5
Energy Reduction	€ 0	€ 84	€ 40	€ 88
Reduction CO2	€ 0	€ 24	€ 12	€ 26
Quality of life	€ 0	€ 0	€ 0	€ 0
Balance external effects	€ 0	€ 114	€ 54	€ 119
Indirect effects				
Labour market	€ 0	+PM	+PM	+PM
Dutch ports	€ 0	+PM	+PM	+PM
Increased competition	€ 0	+PM	+PM	+PM
Balance indirect effects	€ 0	€ 0+PM	€ 0+PM	€ 0+PM
Balance total	-€ 2.379	€ 125 +/-PM	€ 201 +/-PM	€ 115 +/-PM

The additional costs of ERTMS implementation and maintenance are smaller compared to the null-plus alternative than compared to the null alternative. In this case it is assumed that the null-plus alternative uses electronic interlockings when replacing existing ATB systems. It isn't realistic to assume that electronic interlockings will be used on the complete network if there are no significant benefits, like is the case when only ATB is implemented. ProRail will only use electronic interlockings combined with ATB, if this guarantees a more efficient migration to ERTMS. So without migration to ERTMS, the null-plus alternative isn't a realistic long term alternative. However the comparison to the null-plus alternative also shows the balance of costs and benefits if additional costs of ERTMS implementation are relatively small, like is probably the case when ERTMS L2 can be combined with B-relay interlockings.

When additional costs, compared to ATB implementation, of implementing ERTMS are relatively small and benefits are as large as assumed in this exercise, ERTMS implementation might result in a slight positive cost-benefit ratio. The order of the implementation strategies remains unchanged.

5.1.2 Stakeholder analysis and effects of subsidy levels

Investments in the infrastructure are funded by the government, investments in rolling stock are private, but can be subsidized. The government promised a subsidy of 50% to operators of freight and passenger transport for costs of conversion of rolling stock to ERTMS. The subsidy is given as benefits for the operators are not expected to cover all conversion costs. If benefits for operators appear to be substantial, this could justify a subsidy level of 50%. If, on the other hand, operators hardly profit from ERTMS, this could justify a subsidy level of more than 50%. At this point operators argue that there is no business case and risks are too large to invest in unproven technology.

From this analysis costs and benefits for different stakeholder can be assessed, given the assumptions used. Successively the costs and benefits for operators (cargo and passenger), railway infra managers, travellers and society are discussed.

Passenger operators

Operators are facing costs for equipping their rolling stock with ERTMS. The passenger operators the benefits of ERTMS are presenting themselves in a lower energy consumption and higher exploitation benefits. It is expected that more travellers will use the train when quality, reliability and speed are increasing, resulting in higher exploitation benefits. An improvement of safety (reduction of material damage, delays and accidents with employees) and an improved flexibility to deal with interruptions and delays can also result in benefits for the passenger operators. These benefits are shown in table 5.3.

Tabel 5.3: Costs and benefits passenger operators (mio Euro NCW) compared to the null alternative

	Sector strategy	Natural replacement	Upgrading
Conversion rolling stock	-€ 384	-€ 237	-€ 410
Exploitation benefits	€ 42	€ 34	€ 49
Energy reduction	€ 84	€ 40	€ 88
Safety	+PM	+PM	+PM
Delays	+PM	+PM	+PM
Totaal	**-€ 258 +PM**	**-€ 163 +PM**	**-€ 273 +PM**

Despite some blank spots, a subsidy level of 50 percent seems to be insufficient to stimulate passenger operators to implement ERTMS in their rolling stock. The benefits in our calculations, also including a 50 percent subsidy level, do not outweigh the costs. This becomes stronger, when you take into account that a commercial company uses a higher discount factor and a shorter time horizon, than is used in this SCBA.

Cargo operators

For cargo operators it is assumed in this analysis that the complete rolling stock fleet will be equipped (by natural replacements) with ERTMS in the long term. ERTMS is a necessity for driving international corridors like, Rotterdam – Genoa. Parts of this corridors, like the Betuweroute, are already only accessible for ERTMS equipped train. Besides, cargo operators are expecting travel time benefits of several hours on a route with multiple border crossings.

In the sector and upgrading strategy it is possible that conversion of rolling stock will take place earlier, than would have been the case in the null alternative. Also trains not using the TEN-network need to be equipped with ERTMS in the short term in these two strategies. A big difference with passenger operators is that travel time benefits are collected by the cargo operators themselves, instead of the passengers. Noted should be that travel time benefits of cargo operators are calculated using the same methodology as for passengers. In reality on specific routes benefits will be substantial (>30 minutes) or nil, as cargo trains on route have to wait or don't have to wait for passenger trains passing.

Tabel 5.4: Costs and benefits cargo operators (mio Euro NCW) compared to the null alternative

	Sector strategy	**Natural replacement**	**Upgrading**
Conversion rolling stock	-€ 49	€ 0	-€ 56
Travel time (on national track)	€ 42	€ 31	€ 51
Energy reduction	+PM	+PM	+PM
Safety	+PM	+PM	+PM
Delays	+PM	+PM	+PM
Totaal	**-€ 6 +PM**	**€ 31+PM**	**-€ 5+PM**

Infrastructure manager

The manager of the railway infrastructure faces mainly costs whit the transition to ERTMS. Experiences are showing that the ERTMS signalling system is more expensive for as well construction as maintenance. In the long rung it is expected that costs will decrease. Currently the system validation and developing process are important cost drivers.

In theory ERTMS offers possibilities for cost reductions in construction an maintenance, as less trackside equipment is needed. However, labour costs are a major cost driver in the signalling replacement programmes and aren't expected to decline. Cable pits still need to be dug, a cable less needed in this pit doesn't lead to significant lower costs. A final benefit is a possible improvement of the safety of track workers.

In the long run the signalling system itself can lead to cost reductions, if it becomes cheaper in maintenance and purchase. In the short term however reductions are possible if costs savings are possible on infrastructural measures to increase capacity. In the PHS programme measures are taken to solve a couple of capacity bottlenecks in order to make high frequency railway traffic possible. It might be possible that some of these measures can be executed against lower costs when trains use ERTMS.

Tabel 5.5: Costs and benefits infrastructure manager (mio Euro NCW) compared to the null alternative

	Sector strategy	Natural replacement	Upgrading
Conversion infrastructure	-€ 686	-€ 356	-€ 813
Maintenance infrastructure	-€ 94	-€ 55	-€ 112
Reduction capacity investments	+PM	+PM	+PM
Safety	+PM	+PM	+PM
Total	**-€ 780 +PM**	**-€ 411 +PM**	**-€ 925 +PM**

Travellers

Travellers are having the largest benefits from ERTMS in this SCBA. An improved travel time and time schedule are mainly responsible for these benefits. However the size and possibilities of actually collecting these benefits are unsecure. Additional measures (and costs) like shorter block lengths, adjusting of the time schedule and procedures are needed. There is also a trade off between safety, travel time and capacity. They can be improved all together compared to ATB, but it is limited. Stricter criteria for safety will lead to less capacity or a slower driving speed. A higher speed will cause a larger braking distance needed, resulting in a larger headway and less capacity. The equilibrium of these effects will decide which effects will actually take effect when ERTMS is implemented. The benefits shown, are therefore only indicative.

Tabel 5.6: Costs and benefits travellers (mio Euro NCW) compared to the null alternative

	Sector strategy	Natural replacement	Upgrading
Travel time	€ 654	€ 388	€ 755
Improved time schedule	€ 91	€ 68	€ 103
Delays	+PM	+PM	+PM
Safety	+PM	+PM	+PM
Total	**€ 746 +PM**	**€ 456 +PM**	**€ 858 +PM**

Other effects on society

Besides the direct stakeholders involved in railway traffic, also other parties can have effect from ERTMS implementation. A lower energy consumption will lead to less CO2-reduction. A higher safety level creates also benefits for neighbours of railway tracks and traffic crossing level crossings. Shorter travel times can reduce friction of the Labour market. Finally ERTMS can improve the accessibility of the Dutch railway network for foreign operators. Foreign cargo operators with ERTMS on board can cross on more locations (provided they have the Belgian or German system on board) and ship their goods to more locations in the Netherlands. Improve competition can lead to reduction of rail cargo prices, improving the accessibility and position of the Dutch ports.

International passenger transport has the same benefits as the cargo operators. ERMTS won't have significant effects on competition for national passenger transport. Practically it is not possible to have multiple passenger operators on the same line. Concessions are given to one operator per area. There is no reason to assume this will be different when ERTMS is implemented. Competition to win the concession will probably also not increase: until the complete Dutch railway network is equipped with ERTMS, ATB equipment is still needed in rolling stock. So until then, the selected signalling system won't have any effect on competition to win the concession.

Tabel 5.7: Costs and benefits society (mio Euro NCW) compared to the null alternative

	Sector strategy	Natural replacement	Upgrading
Reduction CO2	€ 24	€ 12	€ 26
Safetyy	+PM	+PM	+PM
Labour market	+PM	+PM	+PM
Accessibility Dutch ports	+PM	+PM	+PM
Increased competition	+PM	+PM	+PM
Total	**€ 24 +PM**	**€ 12 +PM**	**€ 26 +PM**

5.2 Risk analysis

In the different strategies examined in this study different risk are involved. Because the SCBA analysis shows no clear preference for a strategy, the risks involved may play an important role in the assessment of the different alternatives. Risks involved can be of a technical, operational, financial, social, legal or organisational nature. Since there is still much uncertain concerning the technique, technical risks can be considered the largest. There is however a clear interaction between technical risks and financial (costs) and social risks (benefits). Assessing legal risk was no integral part of the study. However, the possible subsidizing of operators requires attention in the light of European rules for state aid. Organisationally there is a large risk: unilateral implementation by government, inframanager or operator leads only to costs, not to profits. Cooperation is essential.

The next part of this section examines the different alternatives more closely on the most important risks: technical/operational risks and their impact on costs and benefits.

Null alternative

A possible risk, cited by different parties involved, is that the knowledge and availability of B-relay technology will decrease over time. Up till now there is no evidence of such an effect. Should this effect however become apparent in the future, then track maintenance can become more time consuming and costly. This possibility is uncertain, and has not been taken into account in the calculations. Recent history has shown that also electronic equipment can become obsolete very quickly.

Another risk is that the costs of ERTMS can decrease significantly in the future. By continuing the use of ATB in the replacement programme Mistral, benefits on certain corridors will be missed, where these could be realised with ERTMS. The current costs of ERTMS seems to outweigh these benefits, but in five years time the situation can be different. This risk is perhaps most apparent on corridors that are an important link between other routes, on which signalling systems have to be renewed in the near future. This is also a risk for corridors where the benefits would outweigh marginal costs for ERTMS implementation in infrastructure (if all trains are already fitted with ERTMS). To capture these benefits in the future, chances are that the costs at that moment (implementation of ERTMS in combination with removing the new bought ATB, and the accelerated depreciation of the ATB system) are larger than the additional costs of ERTMS now.

All project alternatives

All alternatives carry a risk in them that ERTMS L2 benefits are uncertain. There is no empirical evidence of travel time and capacity improvements on conventional lines of the Dutch railway system as a result of ERTMS L2.

Also, all ERTMS implementation strategies have the same risks of large ICT projects. Typical issues are excessive developping costs, problems with specifications and compatibility, delays, etcetera.

There is also a risk involved in the development of market conditions. If no real competition among ERTMS vendors will develop, ProRail will face a growing dependency on its suppliers. If ultimately systems are still vendor specific, only the selected company will be able to supply further development and maintenance services.

Another risk is the chance that an even better/cheaper system (or one that is more adopted to the Dutch situation) will become available in the future. Making it impossible for Level 2 investements to reach a breakeven point. It is expected that ERTMS L3 will be developed in the future. At this moment there is a lot of discussion whether L3 will be better adapted to the Dutch situation or not, especially due to unsolved issues regarding the wireless communication technology. However, if L3 will be implemented in the future, probably little infrastructural adaptation will be needed, but rolling stock will have to be upgraded.

Regarding the wireless communication system, there is also a capacity issue that remains unsolved in Level 2. It is uncertain whether the chosen technique can cope with a large number of trains at busy junctions.

Also, waiting with the implementation until 2015 holds a certain risk. Baseline 3, the version of Level 2 that is available in 2015, might in its first versions have some bugs, just like baseline 2 did (which has been reengineered to its current version 2.3.0d). It might take some time to debug the next version, making benefits in the meantime questionable.

As the retrofitting of trains is more costly than buying ERTMS is new trains, it holds also more risks. If large retrofitting projects encounter problems, additional costs will also be significant. But also small retrofitting projects embody risks: depending on the size of the series converted the unit costs can rise significantly. If smaller batches of series are converted one at a time, then costs of development and certification go up.

Sector strategy

In this strategy the largest risks are:

- Migration from ATB only to ERTMS Level 2 only
- Interdependence of rolling stock/infrastructure projects
- Scale of implementation/point or no return

It is not clear how migration from ATB only to ERTMS L2 only can take place on busy corridors and junctions. If no solution is found, then the need arises to take corridors temporarily out of service or a temporary use of dual signalling is necessary, including additional costs.

By the strict phasing of first implementing ERTMS in rolling stock, then in the infrastructure, an interdependence is created. Almost the complete fleet of rolling stock must be fitted with ERTMS before implementation in the track will start. A delay in rolling stock implementation, means a delay in the whole implementation strategy. Especially on busy corridors that need renewing of the signalling system, and where ERTMS promises substantial benefits, a lack of sufficient rolling stock, means renewing the ATB system, thereby delaying ERTMS benefits or raising costs.

Another risk, compared to the natural replacement strategy, is that a "point of no return" will be reached sooner. By building an `ERTMS-only' system, all new trains must be equipped with ERTMS, even if costs stay higher than ATB and benefits appear to be marginal. The system becomes entirely dependent on (adaptations in) the ERTMS system. This risk can be limited partially by only removing ATB installations, when extensive testing has proven ERTMS to be the smarter option.

Natural replacement

The Natural replacement strategy incorporates risks that are attributable to dual systems. The most important are:

- The implementation and the operational use of dual signalling systems
- Capturing benefits with dual systems.

There is no actual experience with a ATB / ERTMS Level 2 dual fitment in the infrastructure in the Netherlands. There is a chance that there will be operational problems by having both functioning at the same time. It is the question whether both systems, once implemented, can function simultanneously, or that only one can be operational at a time. Technical problems may not even play the largest role, but operations might. It can be difficult for both train operators and traffic control to deal with two different systems.

This problem is most apparent when only a limited number of trains is provided with ERTMS. In that case, a distinction in operational rules between ERTMS and ATB trains can be hard to impossible to implement. If all trains of the same type on a track section use ERTMS (for example all intercities or all "sprinters"), then the use of ERTMS can generate benefits. The ERTMS possibilities further augment, when all trains on a route are ERTMS equipped.

This is also the reason why this strategy has specific assumptions on segregated fleets. Routes fitted with ERTMS are as much as possible used by ERTMS rolling stock. Track side ATB is only necessary as a backup for the case disruptions take place and non equipped trains must be re-routed or have to go to a workshop. If this "stand-by ATB system" however results in not being able to adapt to new functionalities (like on Amsterdam – Utrecht), then a large part of the benefits cannot be realised. Shorter headways at junctions and limiting unnecessary braking are for example dependent on block optimisations, which are not possible or more difficult to realise with ATB.

A last risk is the operational impact of driving with segregated fleets. Planning rolling stock is less flexible, creating the need for additional rolling stock and/or causing higher operational costs. These costs are calculated, but as the exact magnitude of this problem is uncertain, can turn out either larger or smaller.

Upgrading

The risks involved in this strategy are close to those of the sector strategy. Distinctive in nature or in scope are:

- Preparation time for rolling stock
- (Costs of) upgrading

The risk of a delay in ERTMS implementation in rolling stock is larger than in sector strategy, since the preparation time is shorter. An important additional risk of this strategy is the costs of upgrades form version 2.3.0d to baseline 3. Expectations are these costs are limited in relation to the initial rolling implementation costs, but still there is some uncertainty on this issue.

5.3 Sensitivity analyses

This chapter presents several sensitivity analyses. As the uncertainties of costs and benefits are large and some of the assumptions made are having significant effects on the outcome, the sensitivity analyses are very important in the SCBA. Possible risks and optimizations of implementation strategies are becoming more clear. As well general as specific assumptions for the different strategies are analyzed.

5.3.1 General

In this section some general assumptions applying to all implementation strategies are stressed. Subjects stressed are:

- Costs of ERTMS implementation
- Benefits of ERTMS
- Growth of rail transport

Cost figures Arcadis

The costs of implementation of ERTMS in rolling stock are already based on the numbers presented in the second opinion by Arcadis on the 2006 sectors implementation strategy. NS confirmed that these were in line with the most up to date numbers, but costs were expected to fall. Costs of implementation in the infrastructure however are based on figures presented by ProRail. ProRail estimates the costs of the electronic interlockings needed for ERTMS higher than Arcadis does. However, the additional costs of ERTMS are lower. Using these figures results in costs of ERTMS implementation that are higher than in the null-plus alternative, but lower than in the null-alternative.

With the comparison to the null and null-plus alternative the possible range of ERTMS implementation costs seems to be quite complete. The actual costs of the null- and especially the null-plus alternative might change in the near future, but the range of the additional ERTMS implementation costs is quite complete. The upper boundary is formed by the comparison to the null-alternative and will take place if ERTMS specifications won't stabilize and have to be adjusted for every small project. The lower boundary formed by the comparison to the null-plus alternative shows the costs of ERTMS if electronic interlockings would be implemented anyway, because advantages are also seen with ATB, or if ERTMS is going to be able to work with b-relay technology on the open track.

Table 5.8 Cost figures Arcadis

		Compared to null alternative		
	Null alternative	Sector strategy	Natural re-placements	Upgrading
Direct effects				
Costs				
Investments infrastructure	-€ 1.051	-€ 492	-€ 231	-€ 611
Investments rolling stock	€ 0	-€ 433	-€ 250	-€ 466
Maintenance infrastructure	-€ 536	-€ 94	-€ 55	-€ 112
Reduction capacity investments	€ 0	+PM	+PM	+PM
Training costs	€ 0	PM	PM	PM
Total Costs	-€ 1.586	-€ 1.019	-€ 536	-€ 1.189
Benefits				
Interoperability	€ 0	€ 0	€ 0	€ 0
Travel time passengers	€ 0	€ 654	€ 388	€ 755
Improved time schedule	€ 0	€ 91	€ 68	€ 103
Travel time freight	€ 0	€ 42	€ 31	€ 51
Delays	€ 0	+PM	+PM	+PM
Exploitation operators passen-gers	€ 0	€ 42	€ 34	€ 49
Total benefits	€ 0	€ 830	€ 521	€ 958
Balance direct effects	-€ 1.586	-€ 189	-€ 16	-€ 231
External effects				
Safety	€ 0	€ 5	€ 2	€ 5
Energy Reduction	€ 0	€ 84	€ 40	€ 88
Reduction CO2	€ 0	€ 24	€ 12	€ 26
Balance external effects	€ 0	€ 114	€ 54	€ 119
Indirect effects				
Labour market	€ 0	+PM	+PM	+PM
Dutch ports	€ 0	+PM	+PM	+PM
Increased competition	€ 0	+PM	+PM	+PM
Balance indirect effects	€ 0	€ 0	€ 0	€ 0
Balance total	-€ 1.709	-€ 75	€ 38	-€ 112

Using the Arcadis numbers, doesn’t result in a large positive or negative cost benefit ratio. The differences between the natural implementation strategy and other strategies are larger, as Arcadis didn’t clearly specify additional costs for dual signalling systems.

Change in beneficial effects of ERTMS

The largest uncertainty in the ERTMS analysis are the actual benefits of ERTMS. Are they large or insignificant? Can benefits actually be included in a new time schedule? In the Netherlands there is currently no working ERTMS track for regular passenger transport. As well the theoretical benefits as the benefits to be collected in practice are unknown for the Dutch situation. In this sensitivity analysis benefits are shown in a +/- 50% situation.

Table 5.9: Reduction of fifty percent gains in travel time and an improved timetable

		Compared to null alternative		
	Null alternative	Sector strategy	Natural re-placements	Upgrading
Direct effects				
Costs				
Investments infrastructure	-€ 1.173	-€ 686	-€ 356	-€ 813
Investments rolling stock	€ 0	-€ 433	-€ 250	-€ 466
Maintenance infrastructure	-€ 536	-€ 94	-€ 55	-€ 112
Reduction capacity investments	€ 0	+PM	+PM	+PM
Training costs	€ 0	PM	PM	PM
Total Costs	-€ 1.709	-€ 1.213	-€ 661	-€ 1.391
Benefits				
Interoperability	€ 0	€ 0	€ 0	€ 0
Travel time passengers	€ 0	€ 327	€ 194	€ 377
Improved time schedule	€ 0	€ 46	€ 34	€ 52
Travel time freight	€ 0	€ 21	€ 15	€ 26
Delays	€ 0	+PM	+PM	+PM
Exploitation operators passengers	€ 0	€ 21	€ 17	€ 25
Total benefits	€ 0	€ 415	€ 260	€ 480
Balance direct effects	-€ 1.709	-€ 797	-€ 401	-€ 911
External effects				
Safety	€ 0	€ 5	€ 2	€ 5
Energy Reduction	€ 0	€ 84	€ 40	€ 88
Reduction CO2	€ 0	€ 24	€ 12	€ 26
Balance external effects	€ 0	€ 114	€ 54	€ 119
Indirect effects				
Labour market	€ 0	+PM	+PM	+PM
Dutch ports	€ 0	+PM	+PM	+PM
Increased competition	€ 0	+PM	+PM	+PM
Balance indirect effects	€ 0	€ 0	€ 0	€ 0
Balance total	-€ 1.709	-€ 684	-€ 347	-€ 793

As the travel time benefits are the most important factor in this analysis to make ERTMS a profitable investment, a reduction has a large impact on the profitability of ERTMS. As the expected benefits of travellers are lower than in the basic calculations, the growth of passengers is also lower and therefore also the exploitation benefits of the passenger operators are influenced by this effect.

The natural replacement strategy is less harmed by this effect than the other two implementation strategies, as travel time benefits are the smallest in the natural replacement strategy and therefore less sensitive for changes in these benefits.

Table 5.10: Increase of fifty percent of gains in travel time and an improved timetable

		Compared to null alternative		
	Null alternative	**Sector strategy**	**Natural replacements**	**Upgrading**
Direct effects				
Costs				
Investments infrastructure	-€ 1.173	-€ 686	-€ 356	-€ 813
Investments rolling stock	€ 0	-€ 433	-€ 250	-€ 466
Maintenance infrastructure	-€ 536	-€ 94	-€ 55	-€ 112
Reduction capacity investments	€ 0	+PM	+PM	+PM
Training costs	€ 0	PM	PM	PM
Total Costs	-€ 1.709	-€ 1.213	-€ 661	-€ 1.391
Benefits				
Interoperability	€ 0	€ 0	€ 0	€ 0
Travel time passengers	€ 0	€ 982	€ 582	€ 1.132
Improved time schedule	€ 0	€ 138	€ 92	€ 156
Travel time freight	€ 0	€ 64	€ 46	€ 77
Delays	€ 0	+PM	+PM	+PM
Exploitation operators passengers	€ 0	€ 63	€ 51	€ 74
Total benefits	€ 0	€ 1.247	€ 771	€ 1.439
Balance direct effects	-€ 1.709	€ 34	€ 110	€ 48
External effects				
Safety	€ 0	€ 5	€ 2	€ 5
Energy Reduction	€ 0	€ 84	€ 40	€ 88
Reduction CO2	€ 0	€ 24	€ 12	€ 26
Balance external effects	€ 0	€ 114	€ 54	€ 119
Indirect effects				
Labour market	€ 0	+PM	+PM	+PM
Dutch ports	€ 0	+PM	+PM	+PM
Increased competition	€ 0	+PM	+PM	+PM
Balance indirect effects	€ 0	€ 0	€ 0	€ 0
Balance total	-€ 1.709	€ 148	€ 164	€ 167

As well as a decrease also an increase affects the sector and upgrading strategy more than the natural replacement strategy. If benefits from ERTMS are larger than assumed in our basic calculations, ERTMS might result in a profitable investment and the sooner the implementation gets started, the better the results are.

Table 5.11: 50% less passenger growth

	Null alternative	Compared to null alternative: Sector strategy	Natural replacements	Upgrading
Direct effects				
Costs				
Investments infrastructure	-€ 1.173	-€ 686	-€ 356	-€ 813
Investments rolling stock	€ 0	-€ 411	-€ 244	-€ 454
Maintenance infrastructure	-€ 536	-€ 94	-€ 55	-€ 112
Reduction capacity investments	€ 0	+PM	+PM	+PM
Training costs	€ 0	PM	PM	PM
Total Costs	-€ 1.709	-€ 1.191	-€ 655	-€ 1.379
Benefits				
Interoperability	€ 0	€ 0	€ 0	€ 0
Travel time passengers	€ 0	€ 544	€ 316	€ 629
Improved time schedule	€ 0	€ 77	€ 58	€ 88
Travel time freight	€ 0	€ 33	€ 24	€ 40
Delays	€ 0	+PM	+PM	+PM
Exploitation operators passengers	€ 0	€ 37	€ 30	€ 43
Total benefits	€ 0	€ 691	€ 428	€ 800
Balance direct effects	-€ 1.709	-€ 500	-€ 227	-€ 579
External effects				
Safety	€ 0	€ 5	€ 2	€ 5
Energy Reduction	€ 0	€ 70	€ 33	€ 74
Reduction CO2	€ 0	€ 20	€ 10	€ 21
Balance external effects	€ 0	€ 95	€ 45	€ 100
Indirect effects				
Labour market	€ 0	+PM	+PM	+PM
Dutch ports	€ 0	+PM	+PM	+PM
Increased competition	€ 0	+PM	+PM	+PM
Balance indirect effects	€ 0	€ 0	€ 0	€ 0
Balance total	-€ 1.709	-€ 404	-€ 181	-€ 479

The growth figures of passenger transport used in this analysis are provided by the NS. Compared to the different WLO-scenario's and results from a KiM study[120], they are on the upper bandwidth of these studies. However, measures like variable congestion taxes for car traffic per kilometre and the

120 KiM (2007), *Marktontwikkelingen in het personenvervoer per spoor 1991 – 2020.*

execution of the PHS programme, can make these figures very plausible. However if the passenger growth is less than expected, the benefits of ERTMS will fall by € 100 to 150 mio.

5.3.2 Specific analyses for the Sector and Upgrading strategy

In this section some specific assumption made for the upgrading and sector strategy are stressed. These sensitivity analyses show that optimizations of these strategies are possible.

ERTMS preparation in Mistral

One of the assumptions in the analysis is that, as long as ERTMS implementation in the infrastructure doesn't start, all signalling systems will be replaced using the ATB system in the Mistral programme. It is assumed that the interlockings used in the Mistral programme aren't capable of handling ERTMS, It might be the case that the electronic interlockings used in the null-plus alternative are capable of working with ERTMS, but ProRail isn't sure about this. Especially if the signalling systems aren't upgraded to ERTMS within a very short period and a next is on the market.

This assumption causes that the signalling systems in Mistral before 2020 in the sectors strategy and before 2017 in the upgrading strategy, have to be replaced twice before respectively 2043 and 2040. Once using the ATB system and once replacing it with ERTMS. However, if we assume that the signalling system can be prepared for ERTMS implementation, double investments aren't necessary. Initial investments are assumed to be higher (€ 950K[121] per kilometre ATB replacement with electronic interlockings, instead of € 860K for a normal ATB system with electronic interlockings), but the upgrade to ERTMS would cost an additional € 45K[122], instead of the complete € 880K. Compared to the null-plus alternative the additional costs of ERTMS preparation are thus € 90K per kilometre, and compared to the null alternative € 375K per kilometre. The total nominal costs of ERTMS (spread over two phases) for tracks already replaced with ATB systems in Mistral are unprepared € 1455K in the null alternative and € 1740K in the null-plus alternative. Prepared the nominal costs are assumed to be € 995 K.

Besides lower nominal costs, also benefits can be collected earlier resulting in a higher NPV. As the track is ERTMS prepared, it is easier to implement ERTMS and tracks can be upgraded to ERTMS, alongside regular replacements (assumed is that prepared track can be upgraded at the same pace as regular track is being replaced).

Whether it is really possible to prepare current ATB safety and signalling systems for ERTMS implementation should become clear when plateau 1 of Mistral is finished and will be upgraded. The upgradability is demanded by ProRail for Plateau 1, but it is not certain if suppliers can deliver a satisfying solution.

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[121] Costs of outside elements of ATB combined with costs of ERTMS interlocking costs (RBC included) (source: ProRail (2009). *Financiële analyse bij business case Mistral*)

[122] Information by ProRail, costs based on Amsterdam - Utrecht

ERTMS preparation doesn't apply to the natural replacement strategy as investments in ERTMS can start early using dual signalling.

Table 5.12: Prepare tracks for ERTMS in Mistral

		Compared to null alternative		
	Null alternative	Sector strategy	Natural replacements	Upgrading
Direct effects				
Costs				
Investments infrastructure	-€ 1.173	-€ 675	-€ 356	-€ 820
Investments rolling stock	€ 0	-€ 433	-€ 250	-€ 466
Maintenance infrastructure	-€ 536	-€ 102	-€ 55	-€ 127
Reduction capacity investments	€ 0	+PM	+PM	+PM
Training costs	€ 0	PM	PM	PM
Total Costs	-€ 1.709	-€ 1.210	-€ 661	-€ 1.413
Benefits				
Interoperability	€ 0	€ 0	€ 0	€ 0
Travel time passengers	€ 0	€ 699	€ 388	€ 811
Improved time schedule	€ 0	€ 98	€ 68	€ 112
Travel time freight	€ 0	€ 47	€ 31	€ 56
Delays	€ 0	+PM	+PM	+PM
Exploitation operators passengers	€ 0	€ 45	€ 34	€ 53
Total benefits	€ 0	€ 889	€ 521	€ 1.032
Balance direct effects	-€ 1.709	-€ 321	-€ 140	-€ 381
External effects				
Safety	€ 0	€ 5	€ 2	€ 5
Energy Reduction	€ 0	€ 90	€ 40	€ 95
Reduction CO2	€ 0	€ 26	€ 12	€ 27
Balance external effects	€ 0	€ 121	€ 54	€ 127
Indirect effects				
Labour market	€ 0	+PM	+PM	+PM
Dutch ports	€ 0	+PM	+PM	+PM
Increased competition	€ 0	+PM	+PM	+PM
Balance indirect effects	€ 0	€ 0	€ 0	€ 0
Balance total	-€ 1.709	-€ 200	-€ 86	-€ 254

Compared to the null alternative investments are at most € 20 mio lower. The nominal investments are up to € 500 mio lower, but as short term costs are over € 420 K per kilometre higher and only long term costs go down by €880 K, this results in an almost unchanged NPV. However as result of earlier benefits a mistral programme with ERTMS preparation has a better result of 60 to 70 mio than a Mistral programme without ERTMS preparation. It should be noted that this will only happen if the preparation actually means that upgrades to ERTMS can be done against significantly lower costs. This is uncertain yet.

Compared to the null plus alternative the benefits from the possibility of ERTMS preparation are much higher. They would be over € 300 mio. Savings on investments are between 200 to 250 mio, as the additional costs of ERTMS preparation are much lower, because high costs for electronic interlockings are made also for ATB replacements. Implementing once or twice expensive electronic technology makes a larger difference in costs, compared to a situation where the first time cheaper relay technology is used.

Longer implementation period

As mentioned in the previous section, a part of the systems in the sector and upgrading strategy are replaced twice due to an implementation period of 23 year and a missing synchronization with Mistral for the next seven to ten years.

Instead of preparing systems for an ERTMS upgrade now, to avoid these double investments, it can also be decided to postpone ERTMS implementation until the next version moment for natural replacement. This means that benefits will show up later, but investments will also be significantly lower.

The speed of implementation is now more or less equal for all strategies: they all only replace signalling systems following the momentum of natural replacement. Strategies only differ in timing when implementation starts and the use of dual systems the track or having the complete rolling stock fleet equipped with dual systems first.

Table 5.13: Longer implementation period avoiding double investments

	Null alternative	Compared to null alternative: Sector strategy	Natural replacements	Upgrading
Direct effects				
Costs				
Investments infrastructure	-€ 1.173	-€ 309	-€ 356	-€ 366
Investments rolling stock	€ 0	-€ 433	-€ 250	-€ 466
Maintenance infrastructure	-€ 536	-€ 68	-€ 55	-€ 79
Reduction capacity investments	€ 0	+PM	+PM	+PM
Training costs	€ 0	PM	PM	PM
Total Costs	-€ 1.709	-€ 810	-€ 661	-€ 911
Benefits				
Interoperability	€ 0	€ 0	€ 0	€ 0
Travel time passengers	€ 0	€ 572	€ 388	€ 655
Improved time schedule	€ 0	€ 80	€ 68	€ 89
Travel time freight	€ 0	€ 34	€ 31	€ 42
Delays	€ 0	+PM	+PM	+PM
Exploitation operators passengers	€ 0	€ 37	€ 34	€ 43
Total benefits	€ 0	€ 723	€ 521	€ 829
Balance direct effects	-€ 1.709	-€ 87	-€ 140	-€ 82
External effects				
Safety	€ 0	€ 5	€ 2	€ 5
Energy Reduction	€ 0	€ 73	€ 40	€ 76
Reduction CO2	€ 0	€ 21	€ 12	€ 23
Balance external effects	€ 0	€ 99	€ 54	€ 104
Indirect effects				
Labour market	€ 0	+PM	+PM	+PM
Dutch ports	€ 0	+PM	+PM	+PM
Increased competition	€ 0	+PM	+PM	+PM
Balance indirect effects	€ 0	€ 0	€ 0	€ 0
Balance total	-€ 1.709	€ 13	-€ 86	€ 22

When all strategies are following the tempo of natural replacement, the differences in investments between the strategies are getting much smaller. The sector and upgrading strategy are getting much lower costs and seem to score a bit better than the natural replacement strategy. Compared to the null plus alternative the costs of the investments in infrastructure of the sector and upgrading strategy are only € 40 respectively € 45 mio.

Differences are however still not large, especially not within the uncertainty of actual benefits from ERTMS. It does however show that combining replacements with natural replacements is at the current cost level far more interesting than replacing systems many years before actual replacement is necessary. The complete ERTMS system itself doesn't bring enough benefits to cover the costs, however benefits might be large enough to cover the additional costs of ERTMS compared to ATB replacements.

Longer retrofit period

One of the implementation risks of the sector and upgrading strategy is that the 5 year period for retrofitting rolling stock can't be realized. The problem is that all rolling stock needs to be converted before implementation in the infrastructure starts. A delay in rolling stock conversion, means a delay of the complete strategy. This sensitivity analysis shows the effects of this happening.

Table 5.14: Longer retrofit period rolling stock

		Compared to null alternative		
	Null alternative	Sector strategy	Natural re-placements	Upgrading
Direct effects				
Costs				
Investments infrastructure	-€ 1.173	-€ 648	-€ 356	-€ 749
Investments rolling stock	€ 0	-€ 416	-€ 250	-€ 421
Maintenance infrastructure	-€ 536	-€ 82	-€ 55	-€ 98
Reduction capacity investments	€ 0	+PM	+PM	+PM
Training costs	€ 0	PM	PM	PM
Total Costs	-€ 1.709	-€ 1.146	-€ 661	-€ 1.267
Benefits				
Interoperability	€ 0	€ 0	€ 0	€ 0
Travel time passengers	€ 0	€ 581	€ 388	€ 669
Improved time schedule	€ 0	€ 81	€ 68	€ 95
Travel time freight	€ 0	€ 37	€ 31	€ 43
Delays	€ 0	+PM	+PM	+PM
Exploitation operators passengers	€ 0	€ 37	€ 34	€ 43
Total benefits	€ 0	€ 736	€ 521	€ 866
Balance direct effects	-€ 1.709	-€ 410	-€ 140	-€ 410
External effects				
Safety	€ 0	€ 4	€ 2	€ 4
Energy Reduction	€ 0	€ 74	€ 40	€ 76
Reduction CO2	€ 0	€ 21	€ 12	€ 22
Balance external effects	€ 0	€ 100	€ 54	€ 102
Indirect effects				
Labour market	€ 0	+PM	+PM	+PM
Dutch ports	€ 0	+PM	+PM	+PM
Increased competition	€ 0	+PM	+PM	+PM
Balance indirect effects	€ 0	€ 0	€ 0	€ 0
Balance total	-€ 1.709	-€ 310	-€ 86	-€ 308

A delay in the retrofit period doesn't lead to higher costs in net present value; the later investments take place, the lower they are valued. Nominal costs however go up, as more track kilometres have to be replaced twice because natural replacement by ATB systems goes on for a longer time. The benefits are also valued lower as they take effect later. In the end a delay in retrofitting rolling stock has a slightly negative impact in the SCBA.

However, if preparations of replacing signalling systems in the infrastructure are in a advanced stadium and has to be postponed due to a delay in rolling stock conversion, this might lead to significant additional costs. These costs are not included in the analysis and should be able to be covered with contractual agreements.

Fitting new rolling stock also before 2015 with ERTMSAn assumption in the sector strategy is that new trains are not equipped with ERTMS until baseline 3 is ready. This means that new trains bought in the 2010 – 2015 period have to be retrofitted in 2015. If these new trains will be equipped with ERTMS as they come off the shelve, they only need an upgrade.

Table 5.15: Fitting new rolling stock also before 2015 with ERTMS

	Null alternative	Compared to null alternative: Sector strategy	Natural replacements	Upgrading
Direct effects				
Costs				
Investments infrastructure	-€ 1.173	-€ 686	-€ 356	-€ 813
Investments rolling stock	€ 0	-€ 396	-€ 250	-€ 466
Maintenance infrastructure	-€ 536	-€ 94	-€ 55	-€ 112
Reduction capacity investments	€ 0	+PM	+PM	+PM
Training costs	€ 0	PM	PM	PM
Total Costs	-€ 1.709	-€ 1.176	-€ 661	-€ 1.391
Benefits				
Interoperability	€ 0	€ 0	€ 0	€ 0
Travel time passengers	€ 0	€ 654	€ 388	€ 755
Improved time schedule	€ 0	€ 91	€ 68	€ 103
Travel time freight	€ 0	€ 42	€ 31	€ 51
Delays	€ 0	+PM	+PM	+PM
Exploitation operators passengers	€ 0	€ 42	€ 34	€ 49
Total benefits	€ 0	€ 830	€ 521	€ 958
Balance direct effects	-€ 1.709	-€ 346	-€ 140	-€ 433
External effects				
Safety	€ 0	€ 5	€ 2	€ 5
Energy Reduction	€ 0	€ 84	€ 40	€ 88
Reduction CO2	€ 0	€ 24	€ 12	€ 26
Balance external effects	€ 0	€ 114	€ 54	€ 119
Indirect effects				
Labour market	€ 0	+PM	+PM	+PM
Dutch ports	€ 0	+PM	+PM	+PM
Increased competition	€ 0	+PM	+PM	+PM
Balance indirect effects	€ 0	€ 0	€ 0	€ 0
Balance total	-€ 1.709	-€ 232	-€ 86	-€ 314

Fitting new trains with ERTMS seems to be more efficiënt than retrofitting them later. The costs of a future upgrade outweigh the costs of retrofitting trains. Equipping new trains directly of the shelves saves around € 40 mio if ERTMS implementation will become a fact.

5.3.3 Specific analyses for the Natural replacement strategy

Some assumptions do only apply to the natural replacement strategy. The segregated fleet and ability of actually reaping the benefits with a dual signalling system are the most important risks of this strategy. This section stresses these assumptions.

The segregated fleet

The use of a segregated rolling stock fleet is one of the crucial assumptions of the natural replacement strategy. By using a segregated fleet it should be possible to reap the benefits from ERTMS, by using a dedicated fleet for ERTMS corridors, while it is not necessary to convert all rolling stock. However it is hard to estimate which part of the rolling stock fleet should be converted to ERTMS. Also the costs for a loss of flexibility in train operations, compensated by an extra rolling stock buffer, are hard to estimate.

Based on the daily amount of trains, it should be possible to drive corridors like Amsterdam – Den Bosch and Utrecht Apeldoorn, with around 30% of NS rolling stock fitted with ERTMS. However, to maintain some flexibility in scheduling trains especially after a day of interruption in the normal schedule, NS estimates that 50 to 70 percent of rolling stock should minimally be equipped with ERTMS to dedicate ERTMS trains to a couple of specified ERTMS corridors (Amsterdam – Den Bosch, Hanzelijn and Utrecht – Apeldoorn). This sensitivity analysis shows the outcome of different sizes of the segregatedfleet..

Table 5.16: Different sizes of the segregated fleet

	Compared to null alternative			
	Initial partial fleet 0% ERTMS	Initial partial fleet 30% ERTMS	Initial partial fleet 50% ERTMS	Initial partial fleet 70% ERTMS
Direct effects				
Costs				
Investments infrastructure	-€ 333	-€ 338	-€ 356	-€ 380
Investments rolling stock	-€ 174	-€ 196	-€ 250	-€ 300
Maintenance infrastructure	-€ 48	-€ 50	-€ 55	-€ 63
Reduction capacity investments	+PM	+PM	+PM	+PM
Training costs	PM	PM	PM	PM
Total Costs	-€ 555	-€ 584	-€ 661	-€ 743
Benefits				
Interoperability	€ 0	€ 0	€ 0	€ 0
Travel time passengers	€ 252	€ 335	€ 388	€ 448
Improved time schedule	€ 57	€ 60	€ 68	€ 77
Travel time freight	€ 26	€ 27	€ 31	€ 35
Delays	€ 0	+PM	+PM	+PM
Exploitation operators passengers	€ 21	€ 30	€ 34	€ 37
Total benefits	€ 356	€ 452	€ 521	€ 597
Balance direct effects	-€ 199	-€ 132	-€ 140	-€ 146
External effects				
Safety	€ 2	€ 2	€ 2	€ 3
Energy Reduction	€ 26	€ 35	€ 40	€ 46
Reduction CO2	€ 8	€ 10	€ 12	€ 13
Balance external effects	€ 36	€ 47	€ 54	€ 63
Indirect effects				
Labour market	€ 0	+PM	+PM	+PM
Dutch ports	€ 0	+PM	+PM	+PM
Increased competition	€ 0	+PM	+PM	+PM
Balance indirect effects	€ 0	€ 0	€ 0	€ 0
Balance total	-€ 163	-€ 85	-€ 86	-€ 83

The size of the segregated fleet influences costs in as well infrastructure and rolling stock. Costs in rolling stock are higher as more trains have to be converted. The operational costs of the segregated fleet itself are however lower when more rolling stock gets retrofitted on short term, because the segregated fleet has to be maintained for a shorter period.

The costs in infrastructure changes as a larger segregated fleet, means that tracks can be converted earlier to ERTMS only systems, instead of 50 percent dual signalling and 50 percent ATB systems. Besides higher costs, this causes that larger ERTMS fleet also creates more beneficial effect. In the end the differences between a 30 or 70 percent segregated fleet are minimal. It is in this case assumed that with a 30 percent ERTMS fleet, it is possible to get benefits on the specified corridors (and on non specified network kilometres only when at least 85 percent of rolling stock is converted).

Only when trains aren't retrofitted at all, the strategy gets a more negative result. This is because in that case full benefits on specified corridors will show up much later, when a significant part of the fleet is equipped with ERTMS by natural replacement.

Besides the additional rolling stock buffer needed for the segregated fleet, other operational negative effects aren't included. When making the train schedule, more differences between trains have to be taken into account. Also retrofitting smaller batches, costs more per train than retrofitting larger batches. Dependant on the amount of train types retrofitted, cost might be underestimated in this analysis.

If the additional rolling stock buffer needed for segregated fleet is as large as the sector predicted[123], meaning five percent of rolling stock, or € 280 mio, instead of € 100 mio as Arcadis estimated and used in the basic calculations, cost of this alternative are going up. In case of a 70% retrofit of rolling stock, the costs are rising with around € 55 mio, in case of 50% initial retrofit it is around € 65 mio and with 0 or 30 % initial retrofit costs are almost 80 mio higher, as the segregated fleet has to be maintained for a longer period.

100% of natural replacements gets ERTMS

In the basic calculations it is assumed that, until 85 percent of rolling stock has ERTMS onboard, just 50 percent of the naturally replaced systems will get a dual signalling system, the other 50 percent gets ATB in the track. In this case the effects of a 100 percent dual signalling system is shown.

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[123] ProRail (2006), *implementatiestrategie ERTMS.*

Table 5.17: 100% of natural replacements gets ERTMS

		Compared to null alternative		
	Null alternative	Sector strategy	Natural replacements	Upgrading
Direct effects				
Costs				
Investments infrastructure	-€ 1.173	-€ 686	-€ 575	-€ 813
Investments rolling stock	€ 0	-€ 433	-€ 250	-€ 466
Maintenance infrastructure	-€ 536	-€ 94	-€ 91	-€ 112
Reduction capacity investments	€ 0	+PM	+PM	+PM
Training costs	€ 0	PM	PM	PM
Total Costs	-€ 1.709	-€ 1.213	-€ 916	-€ 1.391
Benefits				
Interoperability	€ 0	€ 0	€ 0	€ 0
Travel time passengers	€ 0	€ 654	€ 473	€ 755
Improved time schedule	€ 0	€ 91	€ 81	€ 103
Travel time freight	€ 0	€ 42	€ 37	€ 51
Delays	€ 0	+PM	+PM	+PM
Exploitation operators passengers	€ 0	€ 42	€ 35	€ 49
Total benefits	€ 0	€ 830	€ 626	€ 958
Balance direct effects	-€ 1.709	-€ 383	-€ 290	-€ 433
External effects				
Safety	€ 0	€ 5	€ 3	€ 5
Energy Reduction	€ 0	€ 84	€ 49	€ 88
Reduction CO2	€ 0	€ 24	€ 14	€ 26
Balance external effects	€ 0	€ 114	€ 66	€ 119
Indirect effects				
Labour market	€ 0	+PM	+PM	+PM
Dutch ports	€ 0	+PM	+PM	+PM
Increased competition	€ 0	+PM	+PM	+PM
Balance indirect effects	€ 0	€ 0	€ 0	€ 0
Balance total	-€ 1.709	-€ 269	-€ 224	-€ 314

The benefits of a complete dual signalling system don't outweigh the costs. This shows that the implementation of dual signalling systems should be executed on carefully selected corridors.

No benefits with dual signalling

A major concern using dual signalling systems in the infrastructure is the actual possibility of reaping the benefits from ERTMS. Problems with optimizing block lengths, different rules for ERTMS and ATB trains, getting benefits from ERTMS trains included in the time schedule, might be an obstacle for collecting the possible benefits of ERTMS. On the Utrecht - Amsterdam dual signalling corridor for example, rules for ERTMS and ATB trains will be equal for the forthcoming years, meaning that benefits can't be collected. This analysis shows what happens if benefits are only collectable on 'ERTMS-only' tracks, to be constructed after 85% of all rolling stock is equipped with ERTMS.

5.18: No benefits with dual signalling

		Compared to null alternative		
	Null alternative	**Sector strategy**	**Natural replacements**	**Upgrading**
Direct effects				
Costs				
Investments infrastructure	-€ 1.173	-€ 686	-€ 356	-€ 813
Investments rolling stock	€ 0	-€ 433	-€ 250	-€ 466
Maintenance infrastructure	-€ 536	-€ 94	-€ 55	-€ 112
Reduction capacity investments	€ 0	+PM	+PM	+PM
Training costs	€ 0	PM	PM	PM
Total Costs	-€ 1.709	-€ 1.213	-€ 661	-€ 1.391
Benefits				
Interoperability	€ 0	€ 0	€ 0	€ 0
Travel time passengers	€ 0	€ 654	€ 97	€ 755
Improved time schedule	€ 0	€ 91	€ 0	€ 103
Travel time freight	€ 0	€ 42	€ 8	€ 51
Delays	€ 0	+PM	+PM	+PM
Exploitation operators passengers	€ 0	€ 42	€ 8	€ 49
Total benefits	€ 0	€ 830	€ 113	€ 958
Balance direct effects	-€ 1.709	-€ 383	-€ 548	-€ 433
External effects				
Safety	€ 0	€ 5	€ 2	€ 5
Energy Reduction	€ 0	€ 84	€ 10	€ 88
Reduction CO2	€ 0	€ 24	€ 3	€ 26
Balance external effects	€ 0	€ 114	€ 15	€ 119
Indirect effects				
Labour market	€ 0	+PM	+PM	+PM
Dutch ports	€ 0	+PM	+PM	+PM
Increased competition	€ 0	+PM	+PM	+PM
Balance indirect effects	€ 0	€ 0	€ 0	€ 0
Balance total	-€ 1.709	-€ 269	-€ 533	-€ 314

Benefits of ERTMS implementation will drop significantly if they aren't collectable from dual signalling tracks. In the case the basic assumption, that it is possible to drive a segregated fleet and then collect the full benefits of ERTMS by using dual signalled tracks only with ERTMS trains (and use the ATB system only in cases of disruptions), does not hold, the natural replacement strategy ends up as least efficient implementation strategy.

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Appendix A: Assumptions SCBA calculations

This appendix presents the underlying assumptions of the calculations in this SCBA. This section discusses successively the assumptions for costs aspects, direct effects, external effects and indirect effects. General assumptions for all calculations are:

- Prices are presented in a 2009 price level.
- The discount factor for future cash flows is 5.5%, consisting of a 2.5% risk free interest rate[124] and a 3% risk premium as is common use in Dutch SCBA's.
- The observed period is 2010 – 2060, as within 50 years a new replacement cycle will start (probably using a new type of signalling system) and effects of the current selection of a signalling system won't have an infinite duration.
- Prices are excl. VAT. This means a "burden of taxes" isn't included.

A.1 Cost aspects

Assumptions costs and phasing of infrastructural investments

The scope of the replaced track kilometres is 75 percent of the Dutch network. This is approximately equal to the scope of the sector strategy and the long term scope of the ProRail business case for Mistral. The other 25 percent consists of mainly smaller regional lines where ERTMS L2 wouldn't create any benefits. These regional lines might in the end be equipped for costs or interoperability reasons with a simple ERTMS L3 (or ERTMS-regional) version, or ERTMS L1 which can easily be implemented against low costs. But as these lines are not decisive for the choice of an alternative, these lines are not included in the calculations (of course signalling systems will be replaced at some point, and a decision for a system has to be made at that time, but ERTMS L2 is probably not an option).

As systems are assumed to last 40 years, each year 2,5% of the network (off which 75% is included in this analysis) will be replaced in the null and natural replacement alternative. In the sector and upgrading alternative this is also the case until the implementation in the infrastructure starts. From that point on the complete 75 percent of the network has to be replaced within 23 years (as is the case in the sector strategy of 2006).

When possible tracks mentioned in as well the 2006 sector strategy as in Mistral, are combined. If due to timing synergies aren't possible (the current mistral programme goes up to 2018), tracks will be equipped later at the end of the 23 year conversion period. Tracks in Mistral will only be "ERTMS-prepared" in the upgrading and sector strategy alternative, if they are mentioned in the original sector strategy as important tracks for interoperability, speed or capacity.

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124 Ministerie van Financiën (2007), *kenmerk IRF 2007-0090 M*

All costs are given in costs per track kilometre. The Dutch railway network has a total length of tracks of 6500 km. However most corridors are consisting of more than one track. The number of kilometres of routes or corridors in the network itself is somewhat over 3000 km. The scope of 75 percent of the network in track kilometres means that 4875 km of track has to be equipped with ERTMS. In route km this is about 2000 km (less than 75%) as all busy routes fit within the scope and are consisting of more than one track, and single track routes are all falling outside the scope of the study. A part of the 4875 km of railway track (HSL, Betuweroute and soon Amsterdam – Utrecht) is already equipped with ERTMS. The Hanzelijn, as newly built track, comes on top of the 75% of the scope of the current network.

Table A.1 Costs of replacements in thousand euro's per track kilometre

	Costs per km track
ATB with B-relay interlockings	575[125]
ATB with electronic interlockings	860[126]
ERTMS L2	880[127]
ERTMS L2 overlay/dual signalling	995[128]
ATB with ERMTS prepared interlockings	950
ERTMS upgrade of prepared interlockings	45

Investments in rolling stock

In the Netherlands approximately 1450 different trains are using the railway track. Some trains are consisting of two cabs and are having two ATB train control system (=unit) on board. The number of onboard ATB units in trains on the Dutch railway network is around 1750, according to the most recent investigations.[129] This number corresponds with the 1750 mentioned trains/units in the Arcadis study[130], of which 100 are already equipped with ERTMS. However also newly built trains have to be equipped with ERTMS. The growth of passenger and cargo transport by rail is linked to the number of trains needed. In the basic calculations a nationwide growth of around 20 percent passenger transport and 80 percent cargo transport is assumed to take place, resulting in 2250 ERTMS units needed to equip the complete fleet in 2020. Where the number rolling stock units needed is calculated on basis of a nationwide growth, benefits for passengers are based on corridor specific growth expectations by NS.

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[125] Derived from 2.9 bn for 75% of the network (see table 3.2)

[126] Derived from 4.2 bn for 75% of the network (see table 3.2)

[127] Derived from 4.3 bn for 75% of the network (see table 3.2)

[128] Based on 5,5 mln for the Amsterdam-Utrecht line, the costs of just implementing ERTMS are approximately 45 k€ per trackkm (ProRail estimate given by e-mail, July 2, 2009). For these costs to be applicable electronic interlockings and the RBC have to be in place. ProRail estimates differ for electronic interlockings between ERTMS and ATB. Costs of electronic interlockings for ERTMS are estimated to be higher, as also RBC and its subsystems are an integral part of the "interlocking" estimate (see also table 3.2). These costs add up to 950 k€ per trackkm, combined with 45 k€ a total of 995 k€ results.

[129] Spoorbranche (2009), *Materieel overzicht 11–12-2009*

[130] Arcadis (2007), *second opinion implementatie strategie ERTMS en 160 km/u*

Table A.2 Average investment costs rolling stock ERTMS L2[131]

	Costs per unit
Retrofit of train	€ 240 K
ERTMS in new train	€ 125 K

Maintenance

The costs for maintenance of trackside signalling systems are based on ProRail's business case for Mistral. These cost figures are based on observed values and an assumption for a decline of costs as installed volumes grow. As ATB b-relay volumes can't grow these maintenance costs are expected to remain unchanged. Suppliers of ERTMS systems think the observed costs are correct, but more recent observations should already show lower costs and maintenance costs of ERTMS and ATB will be equalized in a much shorter time than ProRail estimates. This study uses an average of ProRail's costs estimations, shown in table A.2.

Table A.3: Maintenance costs used in SCBA in € per track km

	Outside elements	Other maintenance costs	Total maintenance costs
ATB B-relay	€ 4,200	€ 1,500	€ 5,700
ATB E-IXL	€ 4,200	€ 5,300	€ 9,500
ERTMS	€ 3,500	€ 6,300	€ 9,800

Source: ProRail business case, edited by Decisio

A.2 Direct effects

Interoperability

This effect applies only to international rail traffic, mainly freight traffic. The effect consists of different elements:

- Investment costs in rolling stock: Only one system has to be implemented in rolling stock when the international network is equipped with ERTMS. Nowadays a Thalys has seven systems on board which raises the costs of a train by a million euro.
- Reduction in travel time: it is very expensive to fit cargo trains with ATB and the French system. This means that traction units have to be switched at the Belgium or French border. This causes an increase of the travel time by at least half an hour. Implementation of ERTMS means that the same amount of freight can be transported by less traction units in shorter time.
- Capacity: because trains have to switch traction units at the border, a lack of capacity exists at the border.
- Competition: it is easier for a foreign operator to enter the market when systems are interoperable. This can reduce costs of rail traffic and make the market more efficient.

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[131] Arcadis (2007). *second opinion implementatie strategie ERTMS en 160 km/u.*

For international operability, international agreements have to be made. As these have only been developed for the corridors Rotterdam – Genoa and the HSL-zuid, these are the only corridors profiting from ERTMS. However, ERTMS on these corridors is implemented in all alternatives, so there is no difference between the null alternative and the other alternatives[132]. All other possible benefits from interoperability are dependent from foreign investments. Only within the Netherlands locations can become better accessible for foreign operators on the very long term when the complete network is equipped, but the feeder lines are limited and dependent on foreign investments and the accessibility of most important locations (Amsterdam and Rotterdam) is equal for all alternatives. Effects on interoperability are therefore not further taken into account in the analysis.

Speed and travel time

On a couple of routes the infrastructure is capable of allowing speeds up to 160 km/h instead of the current maximum of 140 km/h[133]. The ATB system has to be adjusted to drive such speeds. However agreements for these adjustments aren't made and it is not certain if these adjustments are possible under European legislation. We therefore assume that speeds over 140 km/h are only possible with the implementation of ERTMS. The routes where an increase of the maximum speed is possible are:

- The "Hanzelijn" (Lelystad – Zwolle) (200 km/h is theoretically possible, but in the analysis the maximum speed is limited to 160 km/h, as a dual signalling system is currently being implemented and there are no agreements made with NS to invest in rolling stock capable of driving 200 km/h)
- Leiden - Den Haag
- Amsterdam – Utrecht (no extra investments are needed, as infrastructure is currently being adapted to ERMTS)
- Boxtel - Eindhoven
- Almere – Lelystad

On all other lines the infrastructure itself (curves, switches, weak foundations, level crossings etc.) is the bottleneck in the maximum speed and not the signalling system. Also the fact that slow and fast trains drive on the same track is a bottleneck. A higher speed means that the fast train will be slowed down by the slow train earlier. We therefore assume that the benefits of 160 km/h only take place on these mentioned corridors. Speeds above 160 km/h (theoretically possible with ERTMS, as ERTMS allows speeds up to 500 km/h) are not foreseen in the Netherlands as much more adjustments are needed in the infrastructure to make this possible.

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132 This is a simplification: with a complete ERTMS network in the Netherlands, foreign operators can distribute their goods over the whole network, instead of just to Rotterdam. This effect is not taken into account.

133 There are plans to run trains at 160 km/h on existing infrastructure (without needing ERTMS). As the realisation of these plans is uncertain, we assume speeds of 160 km/h are only possible with ERTMS.

A major advantage of ERTMS are the continuous speed instructions, instead of instructions in discrete steps. When a track is capable of speeds up to 50 km/h, ATB will give a maximum speed instruction of 40 km/h. On this path a gain in travel time of 25% is possible[134]. The separation of the movement authority and speed control means a shorter travel time between 10 and 30 seconds. Also the fact that the braking instructions can be optimized by train type can lead to a reduction of travel time of several seconds[135]. With ATB the braking instructions are adjusted to the train with the longest braking distance.

On the routes were speeds of 160 km/h are possible the travel time will be reduced by 1 minute (as estimated for Amsterdam - Utrecht[136]), except for Leiden – Den Haag where it is estimated at less than 15 seconds. Gains of the other advantages of ERMTS like continuous instead of discrete speed adjustment, separation of movement authority, optimized block sections and better braking instructions are estimated at 30 seconds per large junction the train passes[137]. The feasibility of this assumption questionable as there are no hard figures of these benefits and especially the possibility of including these improvements of travel time in the time schedule can become a problem. It is not an absolute value of ERTMS benefits, only an assumption when making calculations.

The numbers of current and expected passengers in 2020 per track section are provided by NS. We estimate that all passengers on a track section between two large railway stations will benefit from the 30 seconds travel time reduction and if applicable the speed of 160 km/h. This might be a slight overestimation as not all passengers will pass a large station, or because passengers are using slow trains not driving 160 km/h on tracks where these speeds are possible. However as light slow trains, being able to drive 160 km/h, are getting more popular the latter argument might not hold. Also most passengers will at least pass one large railway station, making it plausible they have some benefits from ERTMS. As the 30 seconds gain in travel time is uncertain itself, sensitivity analysis on this subject are sufficient to also deal with the exact number of people benefitting from ERTMS.

For cargo transport the same gains in travel time are used as for passenger transport. This is probably not realistic as ERTMS will make the difference for rail cargo between waiting for the next train to pass or being able to drive earlier (solving a capacity issue). When driving, cargo trains won't have any significant travel time benefits. In other words, cargo trains will have lot of travel time benefits or none at all (but very dependent on the specific situation on a corridor). The current numbers of cargo

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134 Ministerie van Verkeer en Waterstaat, 11 juli 2008, *Voortgang ERTMS en onderzoek ingebruikname Amsterdam-Utrecht*, VenW/DGP-2008/5196, Bijlage 4, Beantwoording van de vragen over de ERTMS implementatiestrategie van de spoorsector.

135 ProRail (2009), *Brief 'Uitgesteld remmen'*, 11 juni 2009, kenmerk 1446278, van dhr. Klerk (ProRail) aan dhr. Jacobs (V&W)

136 Verkeer en Waterstaat (2007). *Landelijke Markt- en Capaciteitsanalyse Spoor*

137 A rough estimation made in consultation with NS and ProRail; gains of these measures are expected to be the largest at busy stations with many tracks crossing each other.

trains per track section are provided by ProRail. The growth isn't specified per corridor, but based on general expectations.

Improvements in travel time are monetized using the value of time. There hasn't been made a distinction in growth between motives like business, leisure and forensic rail travellers. The value of time for passenger rail transport in 2006 was € 6.80 on average for all motives. To correct this number for inflation and an increase in welfare this is corrected to prices in 2009 with the growth in GDP between 2006 and 2008 (10,3 percent). The same has been done for the value of time of cargo transport.

In the basic calculations the development of value of time of the Transatlantic Market (TM) WLO[138] scenario is used. The development of rail transport might not completely fit to this scenario, but for the passenger and cargo transport expectations it is assumed that specific rail transport stimulating measures, like PHS are taken, while these are not included in the WLO scenario's where the travel time valuation is based on.

Table A.4 Value of time

	VOT 2006 (prices 2006)*	Correction VOT 2009 prices 2009	Yearly increase VOT till 2020	Yearly increase VOT 2020 -2040
Passenger transport TM	€ 6,80	€ 7,50	1,09%	1,20%
Cargo transport TM	€ 1.013,93	€ 1.118,36	0,55%	0,61%

*Source: RWS SEE *Personen vervoer: groei reistijdwaardering in de tijd* and *Goederenvervoer: groei reistijdwaardering in de tijd*

Increase in capacity

To collect gains from an increase in capacity, there has to be a lack of capacity. The national market and capacity analysis (LMCA) expects shortages in 2020 on de following routes (provided the HSL-Zuid is functioning and freight traffic is rerouted over the Betuweroute):

- The Hague – Schiphol – Almere - Lelystad
- Alkmaar – Eindhoven
- Utrecht – Arnhem/Nijmegen (minor problems)
- The Hague – Rotterdam
- Utrecht – Rotterdam/The Hague (only freight traffic)

The PHS should solve all these capacity issues[139]. So provided the full PHS programme is going to be executed, no capacity shortages are foreseen. However, it might be possible that some measures

[138] WLO stands for welfare and environment. The CPB , MNP and RPB created different scenario's for the development of the Dutch economy and environment, *Welvaart en leefomgeving, 2006*

[139] Conversation with PHS civil servants, may 12th

of the PHS programme are not necessary after implementing ERTMS, but this requires study for each specific situation.

Capacity increases mainly near complex junctions. Because visibility of signals doesn't play a role, block sections can be optimized. They can end closer to danger points and switches, shortened near stations and placed in curves where signals aren't visible[140]. This causes that the time between two trains following each other can be reduced, which increases capacity.

SYSTRA calculated capacity gains of ERTMS from 6 to 12 percent in France. In Holland this will however be much lower as the current ATB system is better optimized. We expect that an increase in capacity of 3 to 6 percent is possible. However PHS is assumed to solve all capacity issues, as PHS ensures sufficient capacity to accommodate all demand in 2020. Therefore there are no capacity benefits in terms of more trains on the same track. Savings on infrastructural investments might be possible, but a detailed analysis of bottlenecks is necessary to draw any conclusions on this subject.

However a possible benefit is a better time schedule. PHS tries to ensure sufficient capacity, with a minimum amount of infrastructural adjustments. A possible consequence of this, is that compromises in the way of achieving enough capacity might have to be made. For example a regular time schedule, with trains leaving every ten minutes, might be impossible. In this analysis it is assumed that on every line in the PHS programme where 6 intercity trains can depart every hour, this will be possible in a 10/10/10 schedule with ERTMS, instead of a 8/12/8/12 schedule without ERTMS. The benefits of this improvement are calculated as follows:

An average of five minutes of waiting time (every ten minutes a train departs) corresponds with 9 minutes of travelling time (multiplied by factor 1.8). For a waiting time of 4 minutes the factor is around 1.9 and for 6 minutes around 1.7[141]. Unplanned waiting time however weighs heavier than planned waiting time; every minute of unplanned waiting time is valued at around 2.5 minutes travel time. If we assume that travellers still have an expected waiting time of five minutes in the 8/12 schedule, the 4 minutes of waiting time are valued at 7.2 minutes travel time. The six minutes however are valued at 11.5 minutes. On average the value of waiting time is 9.35 minutes compared to 9 minutes of the regular schedule. Passengers value the 10/10/10 schedule 21 seconds of travel time better than the 8/12/8/12 schedule.

New passengers and valuation of their benefits

A better time schedule and travel time can attract new passengers. The shorter the travel time becomes, the more people will travel by train. The travel time elasticity gives the change in terms of

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[140] Ministerie van Verkeer en Waterstaat (2008), *Voortgang ERTMS en onderzoek ingebruikname Amsterdam-Utrecht*, brief 11 juli 2008, VenW/DGP-2008/5196, Bijlage 4, Beantwoording van de vragen over de ERTMS implementatiestrategie van de spoorsector.

[141] CPB en KiM (2009). *Het belang van openbaar vervoer*

percentage in passengers in relation to the change in travel time in terms of percentage. The in-vehicle-time-elasticity for local regional rail transport lies between -0.4 and -0.9, for long distant intercity transport the values reach up to -1.6[142]. This means that for long distances a reduction of 1 percent travel time, will lead to 1.6 percent more travellers by train. In this study an average travel time elasticity is used of -1 for all rail passenger transport. The average travel time on a corridor between two large stations is assumed to be 20 minutes. An decrease of 30 seconds of travel time, would lead in that case to 2,5 % additional passengers.

New passengers generate income for the operators of passenger transport. New passengers themselves are also having benefits from ERTMS benefits, otherwise they wouldn't have become new train passengers. However they don't profit as much as existing passengers. A minute of travel time reduction for an existing passenger means a complete minute of additional benefits in terms of travel time. However assuming this minute of travel time reduction, a new passenger might have chosen for the train if travel time reduced with 1 second, but also the 60th second could be the trigger to make switch for this method of transport. Presuming a linear demand curve for the relation between travel time and the amount of passengers, the average new passenger would have made the switch to the train at a 30 second travel time reduction. The other 30 seconds of the minute of travel time reduction is a benefit for the average passenger. This is half the amount of the benefit fot existing passengers. Therefore all travel time benefits for new passengers are valued using the "rule of half": when the train reaches its destination a minute earlier than before, the new passengers will value this minute on average at 30 seconds.

Exploitation benefits

The profit of the NS from passenger related transport on the main railway network in 2008 was € 174 mio[143]. In this study it is assumed that each percentage increase in passengers also leads to a percentage increase of these profits.

A.3 External effects

This paragraph discusses the external effects of the ERTMS implementation. External effects or externalities are positive or negative effects caused by the project, that have no (market) price, and also affect people who are not directly involved in the project.

Safety

ERTMS reduces the number of SPADs (Signals passed at danger) compared to ATB. A reduction between 75% en 85% is possible[144]. This study assumes a reduction of 80 percent. However, the implementation of ATB VV on thousand dangerous points followed in the near future by another

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142 KiM (2007), *Marktontwikkelingen in het personenvervoer per spoor 1991 – 2020*
143 NS (2009), *Jaarverslag 2008*
144 See appendix D.

hundred installations reduces the number of SPADS dramatically. It should reduce the number of SPADS by 50% and reduce the risks of SPADS by 75%. Another benefit of ERTMS is temporary speed limitations on newly constructed tracks or tracks in bad condition. It will also be possible to open or close a certain section of the track for traffic with a handheld terminal, improving the safety of track workers.

Table A.4 Railway safety, numbers

Subject	2003-2007	Yearly	Source
Spads of which resulting in:	1243	248,6	STS passages 2007
Infrastructural damage	164	32,8	STS passages 2007
Derailment	2	0,4	STS passages 2007
Collision between trains	18	3,6	STS passages 2007
Crossing open level crossing	33	6,6	STS passages 2007
Delay	644	128,8	STS passages 2007
Lightly injured travellers	158	31,6	STS passages 2007
Heavily injured travellers	24	4,8	STS passages 2007
Lightly injured employees	8	1,6	STS passages 2007
Heavily injured employees	1	0,2	STS passages 2007
Deceased employees	1	0,2	STS passages 2007
Track workers (all causes)			
Injured		3,6	Trendanalyse spoorveiligheid 2007
Deceased		0,8	Trendanalyse spoorveiligheid 2007
All employees (all causes)			
Injured		23,1	Trendanalyse spoorveiligheid 2007
Deceased		0,7	Trendanalyse spoorveiligheid 2007

The number of SPADS and accidents is assumed to be evenly divided over all tracks in the network, so can be expressed per kilometre. The current ATB VV programme is assumed to cause a reduction of 50 percent of all SPADS (also evenly divided over all tracks). ERTMS will cause a reduction of SPADS of an additional 60 percent.

The costs of SPADS for heavily injured and deceased people will be calculated with statistics from the SWOV and the SPADS reports. The increase in railway transport in included. The number of accidents (without measures) grows with the amount of railway traffic. The costs of material damaged are however unknown. The inspection of the ministry of transport doesn't yet collect these numbers[145] and the railway sector is working on a cost benefit analysis on this issue.[146]

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[145] Ministerie van Verkeer en Waterstaat (2009), *Trendanalyse 2008*

Table A.5 Costs of victims from traffic accidents[147]

Costs of deceased traffic victim	€ 2.750.000
Costs of heaviliy injured traffic victim	€ 275.000
Costs of traffic victims needing first aid	€ 4.950

Source: Kosten verkeersongevallen in Nederland, RWS AVV, 2006

Energy consumption

The trains of the NS use around 1100 mio kWh yearly[148], resulting in an energy bill of around € 70 to € 90 mio yearly. This study assumes costs of 8 cent per kWh. The use of energy causes also CO2 emissions. On average the mix of Dutch energy causes emissions of 413 g/kWh[149]. These emissions are valued against 5,6 cent per kg[150].

The acceleration of a train is responsible for most of the energy consumption on a trip. Maintaining speed costs relatively little energy as the friction from steel wheels on a steel track is low. This means that each unnecessary braking and acceleration wastes relatively a lot of energy. Better speed adaptation to trains in front leads to less unnecessary braking and less waste of energy. An unnecessary stop between two destinations increases the energy consumption with 30 percent on average.[151] However it is not known how much energy ERTMS can actually save. The basic calculations show a reduction of 15 percent, but as well smaller and larger amounts might be possible.

Noise pollution and quality of life

If ERTMS increases capacity and the operators are putting on extra trains, the number of trains passing residential area's is raised. This causes a higher level of noise pollution which decreases the quality of life. Higher speeds can also lead to more noise pollution, however most travel time benefits are a result of a smoother approach of junctions and less unnecessary braking, maybe even lowering noise pollution. As this is a minor effect and capacity is expected to be sufficient in the null alternative, we do not expect any further effects on quality of life and noise pollution.

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146 Camiel Eurlings, brief: aanpak stoptonend sein passages, 30 september 2008

147 Costs aren't specific for railway accidents. Consequential damage of an average road accident is included, but these might differ from consequential railway damage (in terms of delays, material damage etc.)

148 Website: http://www.senternovem.nl/projectengalerij/Overzicht/Energie_en_Klimaat/NS.asp

149 CE (2008), *Achtergrondgegevens Stroometikettering*

150 CE (2005), *De prijs van een reis*

151 Sierts, Wiersema, Lindhout (2007). *Economisch spoorverkeer met de integrale groene golf.*

A.4 Indirect effects

Market shift

A better supply of rail traffic might lead to a modal shift on the mobility market. Less road traffic, leading to less congestion, pollution and accidents on the road might follow. Modal shifts might also take place on air and sea traffic. As demand is already met in the null alternative, these effects will not be very large. A further quality increase can however attract additional motorists. These effects are generally hard to quantify and monetize. In this study they are described qualitatively.

Labour market

If ERTMS shortens travel time this influences the mobility of people and the area they're looking for jobs. Friction in the labour market can be reduced this way, which leads to a lower level of unemployment. However also this effect is assumed to be small.

Dutch ports

A better accessibility of the port of Rotterdam can improve the competiveness of the Port of Rotterdam. The implementation of ERTMS causes that trains don't need the ATB system onboard anymore, which makes the Port of Rotterdam accessible for more trains. However foreign electric trains also need the 25KV overhead wire. The real increase in accessibility comes when more international corridors are equipped with ERTMS. This however doesn't differ in the null alternative and the implementation strategies. Accessibility of the Dutch ports plays a minor role.

Increased competition

More possibilities for international competition can reduce prices for international transport. When ERTMS is implemented in more EU countries, even competition on national markets is possible when concessions are granted. However these benefits are highly dependent on foreign investments. The Dutch ERTMS implementation on its own doesn't lead to large benefit.s

Assumptions: The indirect effects are hard to estimate. Less attention to these effects will be given, as the main reason for implementing ERTMS are the direct effects. They will be quantified as much as possible, but probably most effects result in a qualitative description.

Appendix B: Nominal values

In this appendix the nominal values of this SCBA are presented in an as much as comparable way as in the letter to the minister of transport of July 16th 2007 which is an supplement on the 2006 sector strategy. This means that cash flows for a period of 25 years are presented from the moment where implementation in infrastructure starts. Conversion of rolling stock in the years before are also presented.

Nominal values compared to the 2006 sector strategy

	ProRail, July 16th 2007	Sector strategy	Natural replacement	Upgrading
	2012 - 2037	2020-2045	2015-2040	2017-2042
Kosten t.o.v. nul				
Infrastructure	€ 600	€ 1.983	€ 1.157	€ 1.983
Rolling stock	€ 280	€ 429	€ 414	€ 466
Maintenance	€ 38	€ 260	€ 93	€ 256
Totaal	**€ 918**	**€ 2.672**	**€ 1.664**	**€ 2.705**
Kosten t.o.v. nul plus				
Infrastructure	€ 600	€ 130	€ 249	€ 130
Rolling stock	€ 280	€ 429	€ 414	€ 466
Maintenance	€ 38	€ 62	€ 2	€ 77
Totaal	**€ 918**	**€ 621**	**€ 665**	**€ 673**
Baten				
Travel time passengers	€ 250	€ 1.810	€ 683	€ 1.725
Improved time schedule	-	€ 251	€ 123	€ 234
Travel time cargo	-	€ 118	€ 57	€ 118
Exploitation passenger operators	€ 50	€ 115	€ 56	€ 112
Safety	€ 25	€ 13	€ 4	€ 12
Energy	-	€ 228	€ 68	€ 204
CO2 reduction	-	€ 66	€ 20	€ 59
Reduction infrastructural investments	€ 350	€ 0	€ 0	+PM
Totaal	**€ 675**	**€ 2.601**	**€ 1.010**	**€ 2.465 +PM**

The largest differences between the 2006 sector strategy and this SCBA are in the infrastructural costs and travel time benefits. Differences in the infrastructural costs are mainly caused by new insights in costs and the fact that the costs of more expensive electronic interlockings weren't included in the 2006 sector strategy. Differences in travel time benefits are caused by the fact that the 2006 sector strategy wasn't a SCBA were travel time benefits were calculated and valued using specific assumptions. It was just a rough guess to show possible benefits from ERTMS.

Appendix C: Expected developments of ERTMS

Baseline 3.0.0

Implementation of ETCS in various countries has shown that the functional and system requirement specifications (FRS and SRS) were far from comprehensive or could be interpreted in various manners. Facing different issues in different contexts, railways and suppliers have implemented different solutions. Even if this affects only a very small part of ETCS, it prevents interoperability.

SRS 3.0.0 being the result of these experiences and of lengthy appraisal should be a more stable specification which will includes the change requests of many stakeholders. It will also consider “limited supervision”, an use of ETCS equipment to provide not full ETCS performance, but only the level of safety of heritage train supervision systems.
The main advantages of limited supervision are:

- At least equivalent level of safety as with existing systems
- Full interoperability (at least expected as such)
- Easily adaptable to existing signalling (requires only the same data as the ones provided to the existing system).

However, Netherlands, with their ATB system does not seem to be a good candidate for limited supervision which is essentially based on Level 1 and the use of balises.

Infill for Level 1

Infill[152] for Level 1 by means of balises is no problem.
However, only a continuous transmission mean can offer the same flexibility as Level 2 or e.g. ATB. This is of importance at the approach to stop signals (hoofdseinen).
The question of the so-called Euroloop is now solved, and there is an agreement about the transmission frequency. The only supplier is Siemens and the “loop” is in fact a radiating cable laid on the foot of a rail.
The other solution, radio infill, has up to now not been used in revenue service. It relies on GSM-R and is channel consuming as Level 2. However the availability is not critical (except if the signal has been unexpectedly replaced to red, the lack of information means that the train will not be informed of the signal being cleared). Therefore, GPRS is a promising solution; there is no need to wait for a proven GPRS solution for Level 2.

GPRS for Level 2

Level 2 requires a permanent radio link between the RBC and any “awakened” train equipment. By comparison with public GSM, it means an enormous number of occupied channels for a very small number of users. By comparison with basic applications of GSM-R, Level 2 demands a better quality of service and far more channels.

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152 Infill is the use of an additional transmission system between the Level 1 balise groups located with the lineside signals.

Beside costs, there are problems in huge stations. To say it simply, Level 2 may not be possible in many railway nodes, because the number of channels is limited.

GPRS, which allows the sharing of a channel by several trains may be the solution, provided its availability and reliability meets the safety criteria of ETCS, which has still to be proven.

Remark: a more simple solution to save channels would be to use Level 1 or simply no train protection system in shunting and marshalling areas. This would require a minimum of shunting signals, and many specialists think it would be a more appropriate solution than Level 2 in such areas.

Level 3

Level 3 differs from Level 2 in that it dispenses from any train detection devices. The system entirely relies on the locations that the train communicates for its front and its rear.

In level 2 you can rely at any time on the trackside train detection devices to know whether a section of track is free or not. This is entirely true for track circuits that give you the real state as soon as they are switched on. This is less true for axle counters which cannot give a "track free" indication from the very beginning. Axle counters have to be "initialised" or reset.

The self-location by the on board equipment raises several issues:

- The accuracy of the location of the train front. It is not only used for the speed supervision, but is also of importance for the interlocking and/or the block system. However the accuracy reached for Level 2 may be deemed sufficient.
- The reliability of the data link. There is a variable called T_NVCONTACT which defines the maximum safe time without any data received from the RBC. It affects directly the required Quality of Service of GSM-R. Some railways require it to be short, as data have to be updated as quickly as by existing systems (especially when data are continuously transmitted by means of track circuits as with ATB or TVM). Other ones accept very long values as the train is supposed to run safely as long it is within the limits of a received movement authority.

  For Level 3 the situation is similar to Level 2 from a safety point of view:
  - a given movement authority will be considered as locked by the interlocking, and the train can move safely within its limits, so there is no urgent need to report the progression of the front of the train
  - the rear of the train will be considered to be still at the last reported location, so the distance between the last reported location and the EOA will be regarded as unavailable.
  - But the minimum headway will depend from the quick updating of the train position, thus requiring a very frequent data exchange between train and RBC.
- The reliability of the indicated position of the rear of the train with two issues: train length and train integrity. These can be easily solved for fixed train consists and even multiple units.

  On the other hand there are major issues for trains of variable consist, especially for freight trains.

  What happens if the train driver makes a mistake when entering his train length? There can be an error of several hundred meters. Should we consider all passenger and freight trains has having the maximum permitted length?

  What happens if a train looses one or several wagons? Of course, this will most likely be perceived soon or later, but in the meantime, the affected track section may have been declared as cleared ("free").

  There are various proposals for systems proving the train integrity and even assessing the train length, but up to now no solution has been found compatible with the required ETCS safety level.

- The issue of resetting the system after a major failure. Even if we can consider that the trains are still able to give their correct position, how can we be sure that the RBC (and hence the interlocking) does not miss any failed train, non equipped train, any standing wagon, etc.? Recovering from a failure may be a lengthy and potentially dangerous process, unless the system is simple enough to be mastered by a single person.
  Therefore it is our opinion that Level 3 will be first used on lines with simple layout and preferably fixed consist or multiple unit trains, or on plain lines between stations.
- The issue of ignoring any unequipped train or vehicle. In this respect the accident on the Transrapid test track in Emsland has been qualified as the “first Level 3 accident”. Of course, the signalling system is not ETCS, but it works the same. A non equipped maintenance vehicle was ignored by the system and could not be known by it. Only procedures could have prevented the Transrapid test train to run, and procedures are subject to human failure, even with such a basic system as the Emsland one (1 maglev train only!).
- The question of improved line capacity is discussed in the relevant section.

The development of Level 3 has been suspended for years.

ERTMS Regional

Our opinion concerning the use of ETCS Level 3 on lines with simple layout is exemplified by the development of ERTMS Regional. This is basically Level 3 applied to the simple requirements of low density lines. The aim is to have a system (almost) as safe as on main lines for a low investment. Capacity is not a problem, and trains need not exchange data when between stations. Train integrity will be monitored by the driver, assuming that any wagon loss will be detected soon enough. Such lines are today often supervised by a single man. In case of a major failure, he will be able to master the situation with help of the drivers.
Presently ERTMS regional is being implemented in Sweden by Banwerket and Bombardier.

Other developments

There are many developments aiming at improving ETCS, many of them using location by means of satellites (e.g. Locoprol, “virtual balises”). It is not the place to discuss the advantages and issues of train location by satellite. Moreover these proposals are not fully compatible and interoperable with ERTMS and they are mentioned only for the record.

Appendix D: Safety Benefits of ETCS

Safety of ETCS itself

Safety Integrity Level

ETCS has been specified for a probability of dangerous failure less than 2 10^{-9}/ hour/ train[153] which corresponds to the commonly admitted values for SIL 4 (better than 10^{-8} per hour).
ETCS should therefore be as good as any modern signalling system.
The danger is even smaller as a random failure will in most cases affect only a data processing or a data transmission and will be corrected at the next step.
However, as it is the case with any computer-based system, “built-in” failures cannot be excluded (software errors or parameter errors, not to speak of possible weakness in the functional specification). Such errors have already resulted in potentially dangerous situations on existing systems. Due to the complexity of the functions performed, it is almost impossible to test all cases with all sets of values.
However, we will not consider further that ETCS may have any impact on the safety level of the signalling system as a whole.

Reliability and integrity of the input data

This is an issue which is very difficult to quantify. Data may be input either by the “signaller” or by the train driver.
The signaller will have the possibility to impose a traffic stop or a speed restriction almost instantaneously. This will increase marginally safety. On the other hand, the method of imposing speed restrictions without lineside signalling only by a dialogue may be prone to errors (wrong kilometre, wrong track).
The train driver will have to enter the train characteristics for trains of variable consists. There may be errors. Of course there may be nowadays errors when computing the trains characteristics (a manual procedure), but in the case of ETCS an error will also affect the displayed signalling information, not only the speed supervision process.
The related risks are rather controversial, an important issue for some countries, an unnecessary worrying for others; they are mentioned here only for the record.

Level 3

We have addressed the safety issues linked with Level 3. They cannot be ignored, and it is clear that ETCS Level 3 shall not be and will not be implemented until a satisfactory solution has been developed.

ERTMS-Regional

The issues are similar to that of ETCS Level 3, except that it applies to low traffic lines and that some issues may be solved easily (e.g. train length may be always the maximum one).

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[153] As mentioned in Subset-091 V 2.2.11 in § 4.2.1.10. This applies exclusively to the ETCS architecture, excluding any external equipment such as brakes.

Safety increase by ETCS concerning overrunning stop signals

Stop signal overruns in the Netherlands

The Inspectorate of the MVW has issued annual reports on SPADs (signals passed at danger) or "STS-passages" with the classification of primary and secondary causes[154]. We use here the 2007 report.

The following tables give the number of SPADs since 1996 and for 1254 SPADs in the database the primary causes.

Table 1 - SPADs since 1996

	1996[40]	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Exclusief afgevallen seinen						264	256	265	284	248	287	275
Afgevallen seinen						36	64	50	64	141	140	125
Inclusief afgevallen seinen	159	202	225	229	275	300	320	315	348	389	427	400

Table 2 Primary causes for SPADs

	Aantal
Waarnemen	823
Waarnemen voorafgaand sein	64
Rembediening machinist	1010
Bedienen van treindienstleider	57
Miscommunicatie	99
Verwachting	347
Afleiding	340
Procedure boord	235
Procedure wal	41
Technische omstandigheden	187
Totaal	3203

The table lists 3203 causes of SPADS, the number of SPADs being about 1254 (we may suppose the SPADs considered are all the ones in the database). Hence it is obvious that many SPADs have been attributed several primary causes. We cannot know, except when examining in detail every SPAD, whether eliminating any one of the causes would alleviate the danger of SPAD. Therefore we will concentrate on the main primary causes (hoofdoorzaken), assuming that eliminating it would have prevented the SPAD.

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154 STS-passages 2007 - Analyse en resultaten over de periode 2003-2007

Table 3 – Main causes of SPADs

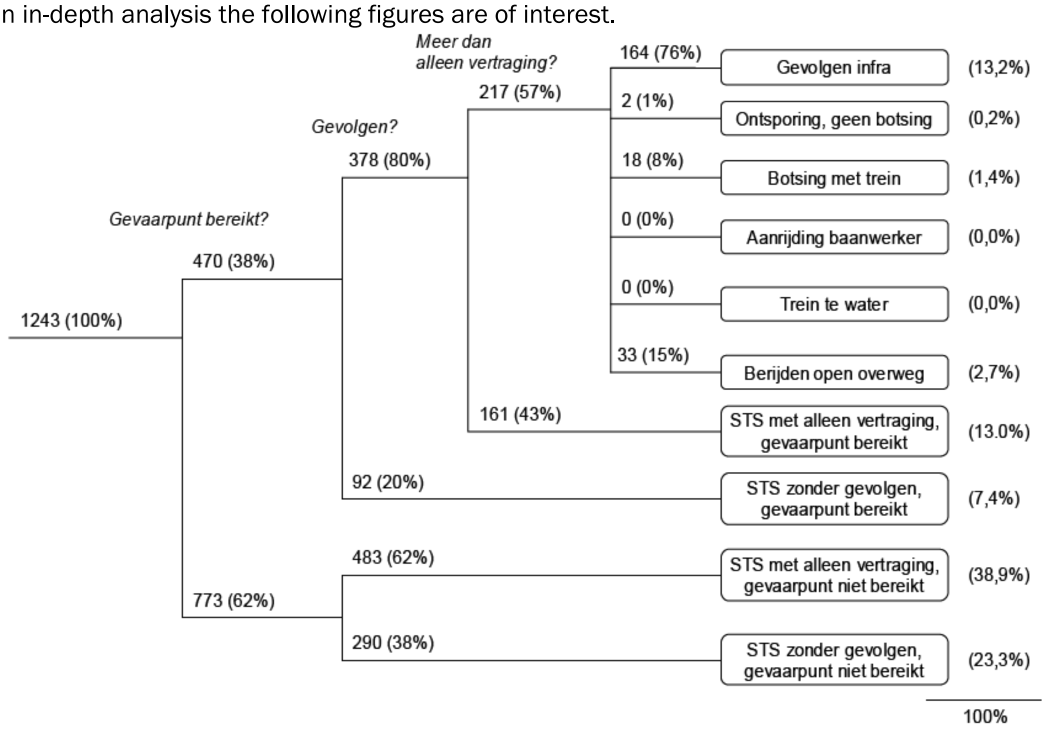
	2003	2004	2005	2006	2007	Totaal
Waarnemen	21	44	35	54	26	180
Rembediening machinist	9	22	16	27	14	88
Bedienen treindienstleider	3	3	9	4	14	33
Miscommunicatie	7	4	7	14	10	42
Verwachting	70	45	30	51	67	263
Afleiding	49	50	36	29	34	198
Procedure boord	36	44	56	32	55	223
Procedure wal	4	9	10	8	10	41
Technische omstandigheden	51	24	24	30	38	167
Waarnemen voorafg. sein	0	6	7	6	0	21
	250	251	230	255	268	1254

(Correct total number of "Waarnemen voorafg. sein – perception of preceding signal" is 19, not 21)

Severity and consequences

The report gives also data about the severity and the consequences of SPADs. For 1243 SPADs the severity and the consequences are given.

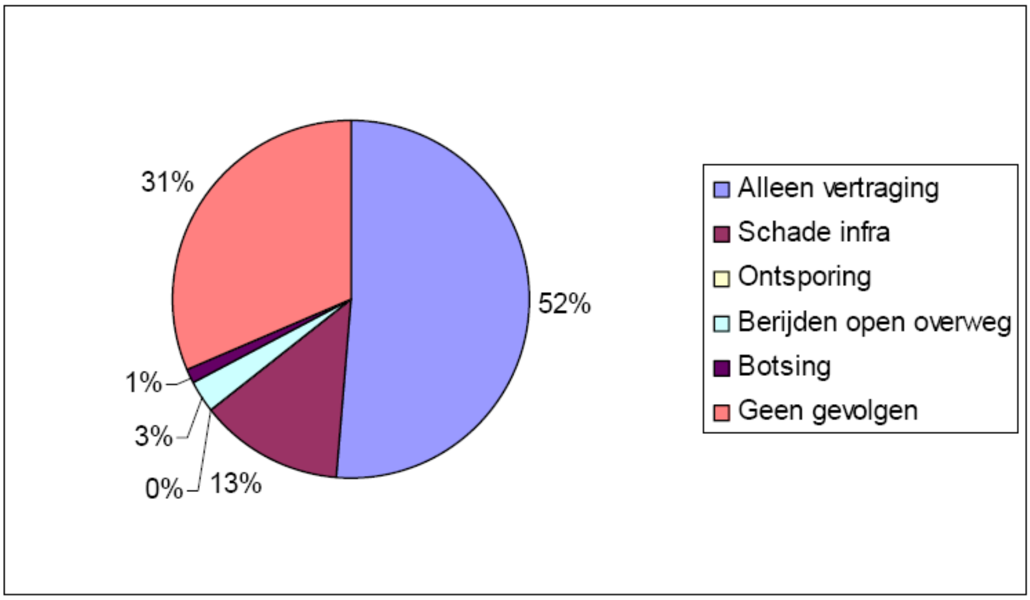
For an in-depth analysis the following figures are of interest.



Figuur 21: Verdeling van gevolgen over de periode 2003-2007 volgens het vlinderdasmodel[18]

(From STS-passages 2007)

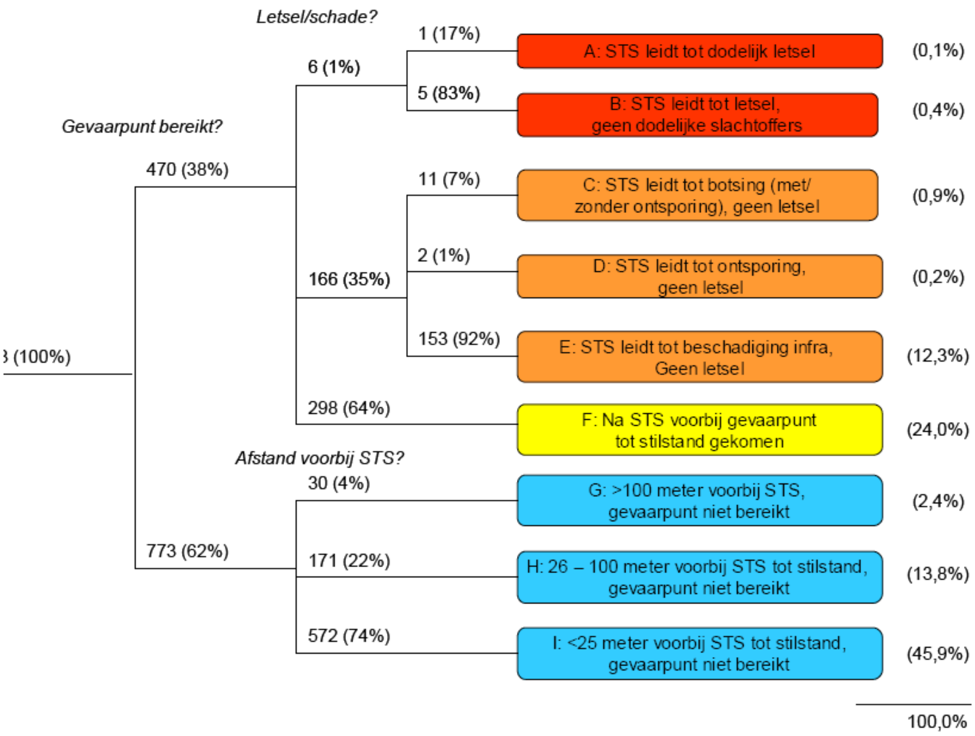
However the synthetic results are sufficient for our purpose:



Figuur 20: Verdeling van gevolgen over de periode 2003-2007[16]

(From STS-passages 2007)

The consequences in terms of severity are given with the following figure:



Figuur 24: Gevolgen op basis van ernstcategorieën

From the 1243 SPADs only one resulted in persons killed (1 railwayman in Roermond on 20 March 2003) and 5 in persons injured (24 passengers severely injured, 158 lightly injured; 1 railwayman severely injured, 8 lightly injured.

We may remark that we do not know about the consequences of passing over a level crossing.

From the two sets of figures we can deduce the following sets of consequences:

- Considering human beings
  - With deaths: 1 1 death
  - With injuries: 5 25 severely 166 lightly
  - Neither deaths nor injuries: 1247
- Considering other damages or costs
  - No consequences: 382
  - Delays only: 644
  - Infrastructure damages only: 164
  - Collisions with another train(rolling stock and possibly infrastructure damages): 18
  - Derailment (Mainly Infrastructure costs, cost for Rolling stock rerailment and possibly repair): 2

Effect of ETCS on primary causes

ETCS will correct driving mistakes made by the driver and alleviate the consequences of:

- lack of reaction
- delayed reaction
- inappropriate reaction

It will not change anything to the ground equipment or the rolling stock failures.

We will consider here the primary causes and examine to which extent ETCS can prevent the effects of these causes or mitigate them.

The primary causes and their definition are recalled hereafter and the possible effect of ETCS indicated:

Table 4 – Effect of ETCS on main primary causes

Primary cause	Description	Efficiency of ETCS in avoiding the causes/ preventing the consequences (overrunning the danger point)
Procedure wal	Het handelen aan de walzijde is in strijd met de regelgeving. Dit kan de treindienstleider of de werkvoorbereider betreffen. B.v. het geven van een onterechte aanwijzing STS.	In most cases, no effect of ETCS. The given example (undue permission to pass a stop signal) will not change. 0 %
Procedure boord	Het handelen aan boord van de trein is in strijd met de regelgeving (b.v. onvoldoende wegbekendheid van machinisten). Dit kan ook de HC betreffen. B.v. het onterecht geven van een vertrekbevel.	Normally covered by ETCS. 100 %
Technische omstandigheden	Technische omstandigheden zijn oorzaak van de STS-passage. B.v. een falend remsysteem, glad spoor, defect communicatiesysteem.	ETCS will not prevent the consequences of a defect on-board system. At the most, it will enforce emergency braking sooner, which may reduce the likelihood of overrunning the danger point. 10 %
Bedienen treindienstleider	De treindienstleider heeft de rijweg herroepen.	ETCS may reduce the likelihood of overrunning the danger point and even the EOA as the train may be informed sooner of a signal replacement (or equivalent). ETCS would then enforce EB, and in some cases stop the train before the stop signal. However such SPADs are not dangerous as such, as a route has been locked in advance of the signal (or EOA) and it cannot be unlocked before a given time lapse (120 s as a general rule) Only possible consequence is delay. ETCS coverage: 10 %

Primary cause	Description	Efficiency of ETCS in avoiding the causes/ preventing the consequences (overrunning the danger point)
Miscommunicatie	Door misvattingen in de communicatie tussen wal en trein ontstaat de STS-passage. B.v. door een slechte gespreksdiscipline begrijpen treindienstleider en machinist elkaar verkeerd: de mededeling was voor trein A bedoeld, maar trein B gaat rijden.	The circumstances of such "wrong communications" do not seem very clear to us. It looks like "procedure wal" except that the ground operator has not consciously infringed the regulations. 0%.
Verwachting	De machinist had het Stop Tonende Sein niet verwacht. B.v. de machinist denkt dat het sein voor spoor 4 voor hem is (want daar komt hij altijd) en op het laatste moment blijkt dat het sein voor spoor 5 voor hem is.	Normally covered by ETCS 100%
Afleiding	De machinist is afgeleid (aandacht is verslapt). B.v. door een technische storing in het materieel bij nadering van een STS.	Normally covered by ETCS 100%
Waarnemen voorafgaand sein(13)	De machinist heeft problemen met het visueel waarnemen van het voorafgaande (geel tonende) sein. B.v. door slecht weer heeft hij niet gezien dat het voorafgaande sein geel toonde en hij dus moest rekenen op stop bij het volgende sein.	Normally covered by ETCS 100%
Waarnemen	De machinist heeft problemen met de visuele waarneming van het stop tonende sein. B.v. doordat het sein in een boog staat, ziet de machinist het sein te laat.	Normally covered by ETCS 100%

Primary cause	Description	Efficiency of ETCS in avoiding the causes/ preventing the consequences (overrunning the danger point)
Rembediening machinist	Het sein is gepasseerd doordat de machinist problemen heeft bij het tot stilstand brengen of houden van het materieel. B.v. de machinist remt te laat of te weinig effectief.	Normally covered by ETCS 100%. But, if it includes mishandling of the brake system by the machinist (may be also in "procedure boord" or "technische omstandigheden") this may not be covered by ETCS[155] Therefore we consider 95% coverage by ETCS

Effect of ETCS on the number of hazards

In fact what ETCS prevents is not overrunning of signal, but overrunning a danger point which is in advance of the End of Movement Authority (EOA).

In ETCS Level 1, the matter is rather clear. The EOA is located with the stop signal. The danger point is the point to be protected (facing switch, fouling point, etc.) It is the end of the overlap for railways that use this concept.

ETCS Level 1 will normally enforce the train to approach the EOA (stop signal) so that it can stop in rear of it. But the speed supervision will cease as soon as the train is under the release speed attributed to the signal. Passing over the signal balise group would then trigger emergency braking unless override permission has been granted. In addition, should the train have exceeded its allowed speed profile (braking curve in this case) ETCS will enforce stopping before the danger point.

With ETCS Level 2 the process is similar with the difference that the EOA is only indicated by a marker board or even not indicated at all. The EOA is at a "safety distance" in rear of the danger point, but it is possible that the safety distance be nil (EOA = Danger Point) with the corresponding consequences for the different braking curves.

In fact we do not know any requirement for the proportion of SPADs eliminated by ETCS. The requirement concerns only overrunning the danger point (the only hazard in terms of safety).

For our purpose about ETCS and safety, we will therefore only consider the overruns. We know that from 1243 recorded SPADs, 470 (i.e. 38 %) have resulted in overrunning the danger point[156]

155 There were in France (at least) two cases of trains having all brakes isolated except in the driving car (resp. the locomotives). The first case resulted in the catastrophe in Paris Gare de Lyon (26 June 1988, 56 fatalities, 57 injured). The second one (28 April 2009) resulted a goods train overrunning a stop signal by some hundreds meters, luckily without consequences. Both cases resulted from gross carelessness of the drivers; the trains have run with cocks closed on the main brake pipe.

156 Inspectie van Verkeer en Waterstaat (2008), *STS- passages 2007,* figure 24

We have no indication about the correlation between the causes of SPADs and the number of effective danger point overruns. However, as an approach for this costs/benefits analysis, we will consider that the number of danger point overruns is proportional to the number of SPADs.
From the preceding, we can estimate which proportion of overruns of the danger point would be avoided by ETCS:

Table 5 – Reduction by ETCS of main primary causes

Aantal STS-passages		Gevaarpunt bereikt (38 %)	Reduction by ETCS	
Waarnemen	180	68	100%	68
Rembediening machinist	88	33	95%	32
Bedienen treindienstlei-der	33	12	10%	1
Miscommunicatie	42	16	0%	0
Verwachting	263	99	100%	99
Afleiding	198	75	100%	75
Procedure boord	223	84	100%	84
Procedure wal	41	16	0%	0
Technische om-standigheden	167	63	10%	6
Waarnemen voorafg. sein	19	7	100%	7
Totaal	1254	474		373
			Corresponding to	**78,7%**

This value is an indication of the effect of ETCS on main primary causes.
It may be underestimated. If we assess the effect of ETCS on all primary causes, the result is quite different:

Table 6 - Effect of ETCS on all primary causes

	Aantal	Reduction by ETCS	
Waarnemen	823	100%	823
Waarnemen vooraf-gaand sein	64	100%	64
Rembediening machinist	1010	95%	959,5
Bedienen van treindien-stleider	57	10%	5,7
Miscommunicatie	99	0%	0
Verwachting	347	100%	347
Afleiding	340	100%	340
Procedure boord	235	100%	235
Procedure wal	41	0%	0
Technische om-standigheden	187	10%	18,7
Totaal	3203		2792,9
		Corresponding to	**87,2%**

Comparison with other systems for signal overruns

KVB in France

As already said, KVB is a balise–based system that performs about the same speed supervision as ETCS Level 1 does. We can expect a similar level of safety, even if KVB has not been designed for SIL 4.

A French official report[157] gives information about the effect on KVB. However the data are such that they can only be used for qualitative purposes only.

The figures address only the “carrés” signals passed at danger. (“Carré” signals, i.e. “squares”, the name coming from the old mechanical signals, are signals protecting routes not set. Passing them at danger may result in collision and/or derailment).

From 1993 to 2006 the number of such “Carrés” passed at danger has been reduced from 144 (1993) to 49 (2006). More important, the number of danger points being passed has been reduced

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[157] Avis du CGPC sur le bilan LOTI du « contrôle de vitesse par balises (KVB) », March 2008.

It is interesting to note that one main reproach from CGPC is the absence of a societal costs/benefits analysis before starting KVB deployment. This may reflect the former long French tradition of the Finance Ministry requiring minimum internal rates of return for railway projects, excluding any societal approach. This is also the result of KVB deployment not being driven by economic reasons, but by political pressure.

CGPC states, not surprisingly, that on the basis of the KVB costs, the society is ready to spend as much as ten times more for avoiding a fatally in railway traffic than for road traffic.

from about 30 to an average of 5 in the last years. It is not mentioned whether in these 5 cases both signal and rolling stock were fitted with KVB.
This period corresponds to the large deployment of KVB, but it started earlier and even now all trains are not equipped. Furthermore, it is not possible to attribute the reduction to KVB only, as many other measures have been taken. But it is clear that ETCS, like KVB would significantly reduce the number of SPADs and especially of passing danger points.

TPWS in UK
TPWS (Train Protection and Warning System) is a basic punctual speed supervision system. It has been deployed as an emergency solution to the increasing number of SPADs in the UK around year 2003. An improved version (TPWS+) allows coping with trains running at speeds up to 100 mph (160 km/h). The success is such that it is considered that ETCS could only marginally reduce further the number of SPADs and that it can no longer be justified by a greater safety.

Other possible safety benefits

Speed limits
ETCS supervise the train maximum allowed speed and the line speed limits.
Excessive speed may result in:

- derailment or overturning
- impossibility to stop before a stopping point.

The latter is dealt with in the section on SPADs (here above) and in the next section (approach to buffer stops).
Derailments or overturning of trains are absolutely exceptional in plain line (speed is limited by comfort and derailment or overturning could only occur at much higher speeds)
The real risk of accident is on:

- very tight curves,
- facing points leading to the diverted direction,
- severe speed restrictions, especially temporary ones.

Such accidents do occur, are very rare and we do not have report of statistical value.

Approach to buffer stops
ETCS can enforce stopping before a buffer stop as before any danger point. We also do not have any statistics. In France frequent collisions with buffer stops occurred in terminus stations (similar to Den Haag Centraal), in most cases with little damage and no injury, but there were some severe accidents.
KVB has almost eliminated such occurrences, and the confidence of the drivers is such that they today approach the buffer stops at much higher speed than they did.
The same can be expected from ETCS, provided balises are installed for relocation before the end of the dead-end tracks.

Appendix E: ETCS and line capacity

Introduction

In a general manner ETCS Level 1 is said to reduce capacity, Level 2 to increase it and Level 3 to offer the best possible capacity thanks to the much heralded "moving block".

Nominal or "static" capacity and practical or "dynamic" capacity

Nominal capacity

Nominal capacity corresponds to the succession of trains with all trains permitted to run at the maximum permitted speed for a given route or line section.

With lineside signalling, this corresponds basically with all trains approaching warning signals displaying the less restrictive indication (i.e. in most cases "green").

With ETCS Level 2 or 3, this means that the displayed permitted speed is always higher than or equal to the one resulting from an unhindered speed profile.

This capacity can simply be evaluated with all trains running at their normal speed profile.

Practical or "dynamic" capacity

Timetables are normally arranged in order that there is no conflict between trains, hence respecting the nominal capacity.

But in everyday's life there are always trains being late, and even a very small delay may result in a conflict between trains. Practical capacity is never as high as the nominal capacity or when it is achieved, it is at the cost of slower running or waiting in rear of stop signals.

Therefore UIC code 406 recommends considering the capacity of a mixed traffic line as being 75 % of its nominal capacity (peak hour) or 60 % (daily average).

Another mean to assess the practical capacity of the line (and the robustness of the timetable) is to carry out "dynamic simulations" with perturbing events. This will reflect the real behaviour of the signalling system and of the trains with a given traffic pattern and a given track layout. However this is only an empirical method. There is no standardised method to make such an assessment.

Level 1 without infill

Level 1 basically transmits information similar to the one displayed by the signals and at the same location.

Therefore Level 1 does not affect the nominal capacity of a line.

But it will affect the practical capacity.

Level 1 reduces line practical capacity because the train receives information only at selected locations (balise groups). The request to stop at the next main signal will remain enforced, even if the signal has cleared in the meantime, until information is updated at the next information point.

ETCS without infill i.e. with information points at signal locations only is the worst case. The train has to pass the next signal at a speed less than the release speed (typically 30 km/h, but much less when the safety distance is short) even if this signal now displays a proceed aspect.

KVB in France has more or less the same constraints. (There is no infill, because a driver could rely on the indication that the signal has cleared, which is not acceptable as KVB is not SIL 4).

The practical capacity reduction induced by KVB in comparison with the previous situation (a warning system only) is considered by RFF as being 10%[158].

Hence we can consider that the average capacity restriction in The Netherlands of Level 1 without infill would be about 10% in comparison with the present situation (ATB)

Level 1 with infill

As Level 1 without infill, Level 1 with infill does not affect the present nominal capacity. However, it may improve the practical one.

Infill with a balise group 400 m in rear of a stop signal: The RWTH study gives only a marginal increase in comparison with Level 1 without infill.

Infill by radio: this can be compared with KVBP an upgrading of KVB with transmission through track circuits in the rear of stop signals. The practical increase in comparison with KVB is some percents.

Level 2

Nominal capacity

Braking later

With Level 2 trains need not to slow down until their actual speed exceeds the permitted speed.

This may happen later and sometimes much later than the location of the warning signal. In the meantime the stop signal may now be “off” (proceed aspect).

In this respect, Level 2 can increase the nominal train capacity.

On the other hand, the driver being informed in advance of track sections not being available may tend to reduce speed too early. This only would affect practical capacity (see below);

Shorter “block” sections

A further increase may be obtained by shorter train detection sections. A Level 2 block section can be much shorter than the usual distance between two lineside signals. And there are no constraints such as number of aspects, signal location and visibility, signal costs.

Moreover, when using axle counters (provided there is no requirement for broken rail detection, as it seems to be the case in NL), block sections can be divided by simply adding an axle counting point.

Effect on nominal capacity without change to the block sectioning

The SYSTRA/SNCF study gives an increase of nominal capacity of around between 1 and 14 %, sometimes more on certain sections with unsuitable block sectioning.

It is very sensitive to the actual signalling layout. The highest gains are obtained where block sections are long (3 aspect block signalling) and therefore the distance from warning signal to stop signal long. High gains are also got where 4 aspect block signalling (green, flashing yellow, yellow, red) has been implemented for one class of trains only (e.g. 160 k/h passenger trains or 100 km/h

[158] as mentioned in the CGPC report

freight trains). Drivers of other trains which are not concerned by the flashing yellow aspect are nevertheless required to brake as soon as they perceive the flashing yellow signal[159].
Increase of capacity is only marginal when the block sectioning has been optimised for the majority of the trains.

Practical capacity

Effect on practical capacity without changes in the block sectioning
The RBC updates regularly (every few seconds) the movement authority.
The train can be informed shortly of any change of the EOA (normally the distance to the new EOA is greater). So even if the train was already braking, the driver may release the brakes and possibly accelerate.
The RWTH study gives valuable information about the capacity increase with Level 2 in comparison with Level 1. However in the Netherlands the sections the most concerned by capacity increase are already equipped with the equivalent of "3 or 4 aspect block signalling". This is very different from the typical signalling layout used by RWTH which reflects German signalling practice (3 km long block sections with 1000 m between the warning signal (voorsein) and the main signal (hoofdsein)
The Systra/SNCF study has demonstrated the benefits of ETCS Level 2 for the robustness of the timetable. Various perturbing situations have been simulated and the cumulated delays compared.
The average reduction of cumulative delays is about 40 % with the same timetable.
The result may be used

- to improve the quality of service (reduced delays).
- to increase traffic by using a higher proportion of the nominal capacity (a perturbation resulting in unacceptable delays in the present situation may result in tolerable delays with Level 2).
- or a mix of both.

The acceptable increase of traffic, with constant delays, varies, depending on the local situations, betwwen 6 (general case) and 12 % (favourable case). But this increase of practiacl capacity is in comparison with KVB. It should be far less when compared withj ATB.

Effect on practical capacity with short train detection sections.
In the Netherlands block sections have a typical length of 1500 m (3 aspect block signalling) or 750 m (4 aspect signalling).
Level 2 allows having shorter block sections without additional lineside signals. We will consider 375 m long block sections on open track, corresponding to a track circuit, or an axle counting section (the RWTH study considers 400 m block sections as prescribed for LZB with short block sections). This length is for reference only, but it is a good compromise between the installation and maintenance costs of trackside equipment and the benefits.

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159 As in the Netherlands they are instructed first to slow down to a speed that is the same as for "running on sight" (30 km/h in France, 40 km/h in the Netherlands) and second to prepare to stop as required.

We must stress, that this supposes that the line is no longer equipped with ATB, as implementing ATB on 375 m track circuits would be cumbersome and expensive[160].

With any kind of signalling system based on track sections, the point to be protected is in rear of the train, at a distance up to the length of the block section, i.e.;

- 1500 m for 3 aspect block signalling
- 750 m for 4 aspect block signalling
- 375 m for Level 2 with short block sections.

This means that the distance interval between two following trains with 375 m block sections will be 1125 m shorter than with 1500 m block sections and 375 m shorter than with 750 m block sections.

The time interval will be reduced proportionally to the speed:

Speed	Time interval reduction in comparison to Level 2 with	
	1500 m block sections	750 m block sections
140 km/h	30,2	9,6
120 km/h	35,3	11,3
100 km/h	42,3	13,5
80 km/h	52,9	16,9
60 km/h	70,5	22,5

As may be seen, for 140 km/h, the time interval reduction is only significant when compared to 1500 m block sections. However, as the most loaded lines are equipped with 4 aspect block signalling, shortening the block sections brings little benefit.

At low speed, the benefits are greater, but in most cases, we are now in station areas where track sections are already short and dictated by the track layout. It will be difficult to further reduce the block lengths.

In stations, the benefits will come from intermediate stop points at block section boundaries that are not presently fitted with lineside signals. (Please see further comments in Appendix C)

On open track, there is no bottleneck and trains are running normally at about their maximum speed, and, as said, the benefits will be small. However, in case of perturbation, the short block lengths will give the opportunity of easier recovering.

Level 3

Level 3 and”moving block”

“Moving block” is the ideal situation in which a train maintains a safety braking distance between his front and the rear of the forerunning train, the known position of which is supposed to be continuously updated.

Level 3, in principle, allows moving block.

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160 We could imagine overlaying axle counters on existing track circuits, but a lot of technical and operational issues would have to be solved.

However the use of continuously variable position for a train is not practical, especially in point and crossing areas. It is much simpler for interlockings to work with track sections and associated logical variables (free, locked, etc.). In fact CBTC systems (the equivalent of Level 3 for urban railways) work generally with “virtual block sections”. In any case there are virtual block sections in point and crossing areas. They are not true moving block systems (and some suppliers have deleted any reference to moving block)

Therefore the position of a train will be a discrete variable. However as it costs almost nothing (only memory and processing time) virtual block sections may be very short, especially in critical locations.

Level 3/Level 2 comparison

We consider the actions when a train has cleared a track section. We suppose here we are in a points and crossings area which is usually a bottleneck with short train detection sections adapted to the track layout.

We only consider the period between the time a train has cleared the track section and the moment when the interlocking is informed. The processes in Level 2 and Level 3 are the following ones:

Level 2:

- train detection system detects track free: 1.5 s to 2 s for a track circuit (depending on the imposed pick-up delay), possibly less for an axle counter

  $t_a = 2$ s

- train detection system reports status change to interlocking.

  t_b depends on the interlocking type.

But we can consider that t_b is far less than 1 s.

$$\mathbf{t_a + t_b < 3\ s}$$

Level 3:

- Not only rear of the train, but also safe estimation of location of train rear must have cleared the track section.

  The safe estimation depends:

  - *the error margin on the train head position: according to specification (subset-041 5.3.1.1), it is less than 5 m + 5*distance travelled since the last balise group. It will be therefore considered as 15 m if the distance travelled is 200 m and 55 m if this distance is 1000 m. We will consider that this error will cost an average of 1 s.*
  - *the error on the train length: it can be considered as zero on fixed consist trains or multiple units. For variable consist trains, the length is today known with a good precision, even for freight trains (wagon lengths are in a database), but it is subject to errors in the number of wagons.*

  In addition the position in report shall be estimated less than 1 s before beginning of sending the corresponding position report (Subset-041 5.3.2.1). This means that it can be 1 s old.

- Train integrity to be proven

The train will use the last integrity report. As there is no accepted technical solution, there are no experience based data. The only specification is the Functional Requirement Specification TIMS issued by the ERTMS Users Group (00E996 version 1 dated 12/10/00).
According to this specification the "tolerable maximum disclosure time" is 4 s (and as much as 30 s for ordinary freight trains (i.e. without electric line) on "main line high traffic density"! A 4 s disclosure time means that the train was complete 4 s earlier. Therefore, unless there is some internal time stamping, the safe position considered for the rear of the train will be the one 4 s earlier.
RWTH take 4 s as the delay linked to train integrity proving. It could be somewhat shorter, but it could be much longer, up to 30 s for freight trains.

- Time to next sending a message to RBC.

  The train will send a position report either

  - *when passing over a balise group*
    OR
  - *at a specified time interval.*

  However Subset-040 4.3.5.1 states "the trackside shall not require position reports at time cycle lower than 5 s." This means that the interval between two messages to the RBC will be more than 5 s.
  Therefore we have to consider these 5 s minimum, unless position reports are requested by suitably positioned balises (but the balises would be "suitably positioned" for one type of train and one type of running profile, leaving a lot of problems to other trains.

- Next step:
  - RBC to take into account track section clear almost immediately, if it can issue a new movement authority without referring to an interlocking

  OR

  - RBC to inform interlocking.

We can then try to assess the time required for the described process. This is not so simple, as many values are minimum or maximum ones. Assuming we are in a congested area with points and crossings there will be an interlocking different from the RBC, but this is not certain. There are many uncertainties about level 3.
From the time the rear of the train clears a given point, a position report indicating this clearance will be sent within about 6 s (5 s MINIMUM between reports + 1 sec MAXIMUM age of position assessment).

However, the train integrity information may be 4 s old. This means that any position assessment less than 4 s old will be rejected. Then we have to wait for another position report, i.e. at least 5 s later. This can sum up to 4 s+5 s=9 s

Hence, neglecting the uncertainties on the position assessment itself (which can be minimised by positioning balises), the clearance report will be considered if it is between 4 and 9 sec old.

We would have then (indicative values only):

	Mean value for ETCS Level 3
Delay related to the error margin on the position assessment of the train	1
Time between actual clerance of a track section and issue of corresponding valid report: 4 to 9 s	6.5
Train to RBC	1.1
RBC to interlocking	0.05
Summation	8.65

We have to compare these 8.6 s to the 3 s for level 2. They correspond to a difference of 5.6 s in favour of Level 2 if the track ssection boudaries are the same, which would be the case in intricated layouts.

5.6 s corresponds to a travelled distance of 155 m at 100 km/h or 218 m at 140 km/h and so on. It is clear that when the train detection sections are long, the advantage is in favor of Level 3. This is obviously the case on plain line. But in point and crossing areas, even if we can argue about some values, especially about the 4 s for train integrity which may not apply to fixed consist trains[161], the advantage is in favor of Level 2.

[161] Until there is a recognised solution for the TIMS (Train integrity Monitoring System), we can only consider the values in the specification.

Appendix F: ETCS and the environment

General

ERTMS as such has very little effect on the environment (dispense of lineside signals, masts for GSM-R, electromagnetic radiations, …). Except the GSM-R base stations which may be a very sensitive issue with the neighbours, other issues are common with ordinary electronic equipment.
Important effects can only be secondary ones, resulting from the running of trains.

Increased capacity

This may result

- in modal transfer
- possibly less tracks and hence less land use

Noise

The only effect could only result from a reduced number of train stops with Level 2 (or 3). Train stops, especially of freight trains, are a source of additional noise through the braking process, the brake release and some shocks.

Energy consumption

ERTMS has little influence. The only noticeable effect results from a reduced number of train stops or speed reductions down to 40 km/h. This applies to Level 2 and 3.

Appendix G: Solving capacity issues with ERTMS: 4 theoretical cases

In this appendix PTADC/Sierts, A. presents several examples of cases where ERTMS play a role in the solution of solving capacity bottlenecks. These examples have not yet officially been verified with ProRail data, but can be a starting point for further studies regarding capacity benefits of ERTMS. According to ProRail's capacity management these examples are illustrative for showing the possibilties of ERTMS implementation. However Prorail mentions that (as also shown in these cases) just introducing ERMTS is not sufficient: block lengths and process optimization, made possible with ERTMS, is needed. Only when these conditions are met, benefits of ERTMS introduction can have the extent shown in these cases.

The principles in the examples shown in the cases below are probably also applicable to other situations in the Dutch railway network. Cost effectiveness has not been taken into account and should be analysed on a case by case basis.

Introduction

In this appendix, five examples describe how ETCS is probably able to increase performance, compared to the classic Dutch signalling & control.

Above all, it is crucial to understand that ETCS is just a track-train communication standard, including standardised protecting facilities at the train. So ETCS itself can only improve communication between track and train, and is able to keep a train from unsafe situations (e.g. speeding, colliding with another train etc.).

Improved safety will have positive economic effects because incidents, damage and casualties are avoided, but – as the railways are already very safe – the railway economical performance will not be significantly improved by this. So for a real performance increase, we fully depend on the positive impact of improved communication. This fact underpins that ETCS should be seen as a process innovation tool, and has all the characteristics of an ICT-innovation. ETCS is a facilitator for process improvement. So the real performance improvement can only be reached if other fields outside ETCS are innovated as well. The most affected fields are planning, track layout design, operational control principles and – as the last in line – the trackside safety system ("detection", "interlocking" and "signalling"). These fields together form the heart of the train operation control.

It might be clear to the reader that improved communication & control using ETCS-standard can only contribute to better business performance, if the current methods and means for railway communication & control have serious drawbacks. Remarkably this is one of the most forgotten issues when analysing performance and economical impact of ETCS. The background of this problem is that most railway engineers and consultants tend to forget why certain principles, methodologies or limitations within the railways are in place. People are used to the current way of working, and do not see a relation between classic trackside signalling principles, and existing planning and operating principles, methodologies, limitations or performance disadvantages. Most people tend to focus on the technical properties of the ETCS-technology from a signalling point of view. This technical point of view hampers the real strategic understanding of ETCS. On the other hand, also the railway process control perspective might look quite complex and hard to understand for outsiders.

Because of this, we present four bottlenecks in the Dutch Railway system, that show the performance limitations of classic signalling & control, and how they can be solved by using ETCS cab signalling. In the fifth case an operational example from Switzerland is presented.

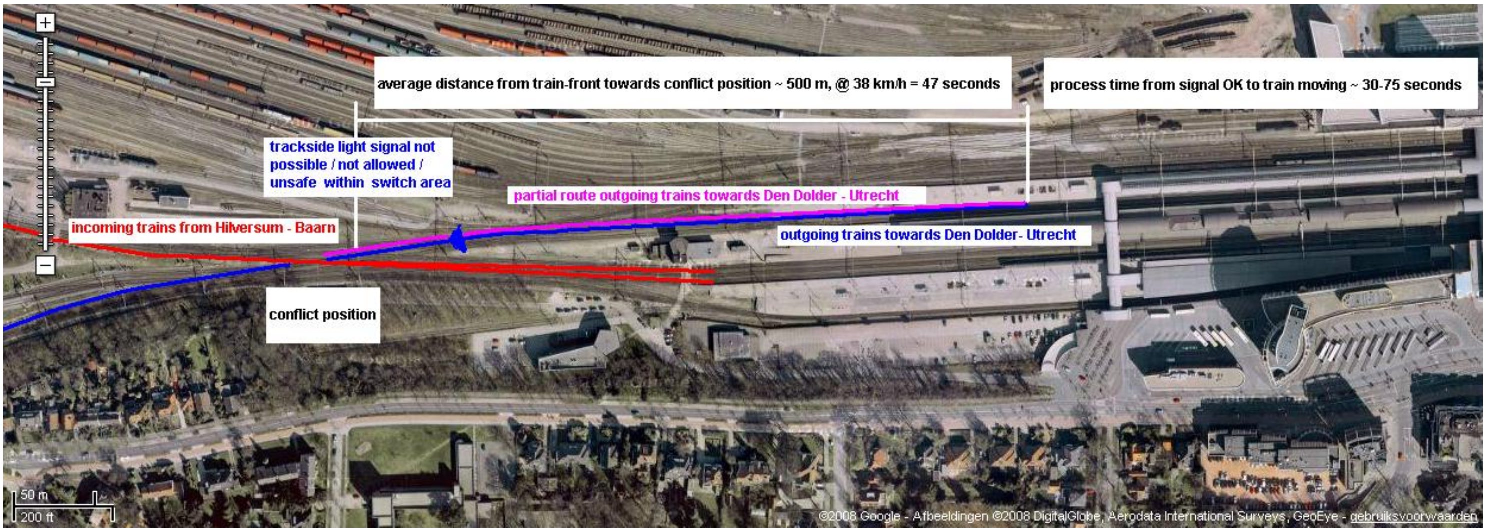
In the examples given, much attention is on the disadvantages of classic trackside signalling, and the impact that these limitations have on railway performance. One of the most highly impacting performance effects of ETCS cab signalling is that cab signalling is able to inform the driver within large switch areas. This improves capacity and reduces delays significantly.

Overview of the five factsheets

- Amersfoort west-side: Cabsignalled partial route *(saves cosly fly-over from LMCA/PHS-programme)*
- Den Haag HS: Cabsignalled partial route *(fly-over was considered too expensive, solved with ETCS)*
- Zwolle IJsselbridge: short block with Dynamic Realtime Slot Allocation *(reduces Intercity time loss)*
- Ommen: cabsignalled station entrance and improved level crossing control *(reduces time loss)*
- Lötschberg Basetunnel Switserland: ETCS level 2 “Green Wave” control *(reduces time+energy loss)*

Case Amersfoort west side: Cab signalled partial route

Source: PTADC. Case is hypothetical as a flyover construction will be constructed in 2013 and ERTMS won’t be available on thime to create another solution.



Problem description:

- Conflict at Amersfoort west-side between traffic flows incoming Hilversum – Baarn – Amersfoort (red) and outgoing Amersfoort – Den Dolder – Utrecht (blue) has almost reached classic normative capacity limitations
- Traffic growth foreseen in LMCA exceeds classic normative capacity limits

Classic solution:

- Fly-over Amersfoort west side
- Identified in Rail 21 (skipped) and recently in LMCA
- Programmed in PHS

The deeper technical and procedural issues behind:

- Classic trackside signalling/ATP cannot signal & failsafe-protect conflict point within switch area
- Therefore a partial route (marked purple, see picture above) cannot be set with classic Dutch signalling, only the blue route can be set
- Next problem is that – if the blue route is set – it takes a lot of time before the train actually passes the conflict point, because:
  - The train conductor is only allowed to start station-leave-process if start signal shows OK
  - So the platform process has to be performed first, before train can actually use route
  - Platform process can take 30 to 75 seconds (estimation)
  - Next problem is the long driving time and low speed from platform to the actual conflict point.
  - Therefore long time slow driving in switch area (35~40 km/h, average 38 km/h, time ~47s)
- Because of these long process and approaching times, it can take approx. 77 to 122 seconds after route availability that the conflict point is really used, which leads to a very poor utilization ratio
- All this time the conflict point is not available for other trains, which can result in long waiting times

Estimations and calculation of process times

- Estimated process time from “signal OK” to “train starts moving” is approx. 30-75 seconds [162]
- *Estimated average distance from train-front until conflict point is approx. 500 meters*
- *Estimated average speed in the switch area is 38 km/h*
- Estimated moving time from platform until conflict point at estimated 38 km/h is 47 seconds
- *Estimated average train length is 270 meter*
- Estimated average physical occupancy time of conflict point based on the previous is 26 seconds
- Assumed time from “conflict point free” to “route set” is 10 seconds *(could be improved)*

Description real-time-control- and cab signalling-principles at Amersfoort west side

- Control: use dynamic train position/speed data for calculating expected unlocking moment conflict point, optimised start-time of platform duties and smart speed advice towards conflict point
- Platform: Use e.g. flashing-white platform indicator to pre-start platform duties
- Start signal: use flashing CS-aspect in trackside start signal for cab signalled partial route
- Partial route signalling & train protection: use cab signalling for “just-in-time-conflict-free” and fully supervised partial route until conflict point (purple route); after conflict point is free, the train will receive the route extension (blue route). [163]
- Can be realised with most technologies for cab signalling (ATBNG, LZB-CIR/ELKE, TBL2, Euro-ATB, ETCS-L1 with infill and ETCS-L2/3), but Euro-based solutions are highly preferable for interoperability and legislation reasons.

Estimation of traffic capacity and delay impact

The current normative process time is 4 minutes [164], which leads to a theoretical maximum capacity of 15 slots. A higher load will lead to excessive waiting times and is considered as unacceptable, but also a 15-slots load is not feasible because of unacceptable constrains to the timetable
Based on a technical process time including time margin of 1 minute[165], a theoretical maximum capacity of 60 slots are available; with a practical 75% load this means 45 slots, which is an increase of 250% compared to the current control principles. Also both average and maximum waiting time will be significantly decreased (maximum waiting time is assumed average physically occupancy time 26s + assumed route set time 10s = 36 seconds)

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162 This value varies very strong

163 Noted should be that: Estimating the time of the conflict area being cleared by the first train is possible. It is a train management function, not an ETCS one. Until the RBC has received and taken into account the information “new route available”, it will send an EOA (end of authority) up to the protected/danger point. The second train should then only start when it is not likely to receive en route a stop order, i. e. It should not approach the protected point at warning distance before the new route be taken into account by the RBC. A margin should be added for the time between RBC messages.

164 Must be verified at ProRail Capaciteitsplanning

165 Not clear is if a process time of 1 minute including a time margin is meant (seems to be very short), or a process time including a 1 minute time margin.

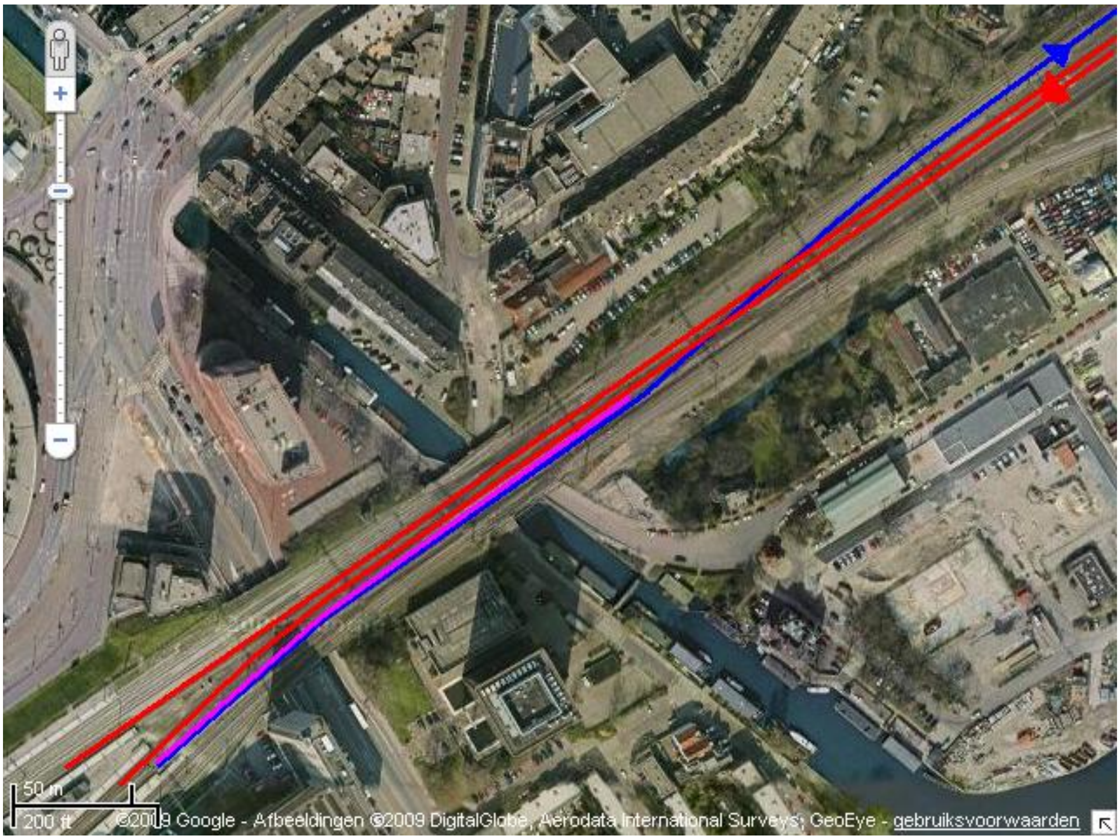
Further optimization is possible when the passing speed at the conflict point is increased and therefore blocking time will be shorter; in this specific case this could be possible when the passing train is fully on straight track (= no wagons anymore in diverting switches) so the maximum speed can be increased using cab signalling.
Also the “conflict-point-free-to-new-route-set”-time, currently assumed to be 10 seconds, could be made a couple of seconds faster, but that’s not really high-impacting

Impact evaluation

- Substantial cost savings & absence of construction hindrance compared to fly-over / dive-under
- Performance satisfies traffic needs in terms of performance, quality and costs
- In line with V&W “Beter Benutten”-policy and ProRail “Triple A” strategy
- Principle also usable for other path conflicts, which would not be helped with a fly-over / dive-under
- Higher costs on switch maintenance / renewal, to be compared with capital costs fly-over
- Concept can be used in all other main Dutch stations; this will clearly result in a significant improvement of punctuality on the whole Dutch railway network

Case Den Haag HS north-side: Cab signalled partial route

Source: PTADC



Problem description:

- Conflict at Den Haag HS northeast-side between traffic flows incoming Laan van NOI - Leiden (red route) and outgoing Den Haag HS towards Den Haag Centraal (blue route) has almost reached classic normative capacity limitations
- Traffic growth foreseen in LMCA exceeds classic normative capacity limits

Classic solution:

- Fly-over
- Identified in LMCA, but skipped because of strong negative cost-benefit-ratio
- Not programmed in PHS but capacity; train delays will increase

The deeper technical and procedural issues behind:

- Same problems as described in Amersfoort west-side case: classic trackside signalling/ATP cannot signal & failsafe-protect conflict point within switch area, therefore the purple marked partial route cannot be set with classic Dutch signalling, only the blue marked full route is possible

- Same problem with platform process: takes 30 to 75 seconds after route available (estimation)
- Same problem with long driving time and low speed from platform to the actual conflict point, estimated average distance 350m @ 38 km/h, resulting driving time ~33s)
- Because of these long platform process and approaching times, it can take approx. 66 to 88 seconds after route availability that conflict point is really used, which lead to a poor utilization ratio
- All this time the conflict point is not available for other trains, which can result in long waiting times and delays following the red route

Estimations and calculation of process times

- Estimated process time from “signal OK” to “train starts moving” is approx. 30-75 seconds [166]
- *Estimated average distance from train-front until conflict point is approx. 350 meters*
- *Estimated average speed in the switch area is 38 km/h*
- Estimated moving time from platform until conflict point at estimated 38 km/h is 33 seconds
- *Estimated average train length is 270 meter*
- Estimated average physical occupancy time of conflict point based on previous is 26 seconds
- Assumed time from “conflict point free” to “route set” is 10 seconds *(could be improved)*

Description real-time-control- and cab signalling-principles

Control: use dynamic train position/speed data for calculating expected unlocking moment conflict point, optimised start-time of platform duties and smart speed advice towards conflict point
Platform: Use e.g. flashing-white platform indicator to pre-start platform duties
Start signal: use flashing CS-aspect in trackside start signal for cab signalled partial route
Partial route signalling & train protection: use cab signalling for “just-in-time-conflict-free” and fully supervised partial route until conflict point (purple route); after conflict point is free, the train will receive the route extension (blue route)
Technology: can be realised with most technologies for cab signalling (ATBNG, LZB-CIR/ELKE, TBL2, Euro-ATB, ETCS-L1 with infill and ETCS-L2/3), but Euro-based solutions are highly preferable for interoperability and legislation reasons

Estimation of traffic capacity and delay impact

- Same as Amersfoort west-side case

Impact evaluation

- A fly-over-construction showed an unacceptable negative cost-benefit-ratio, but this control-solution will be millions Euro cheaper. This might result in a positive ratio.
- Performance satisfies traffic needs in terms of performance, quality and costs
- In line with V&W “Beter Benutten”-policy and ProRail “Triple A” strategy

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[166] This value varies very strong

The Ommen-case

Source: PTADC

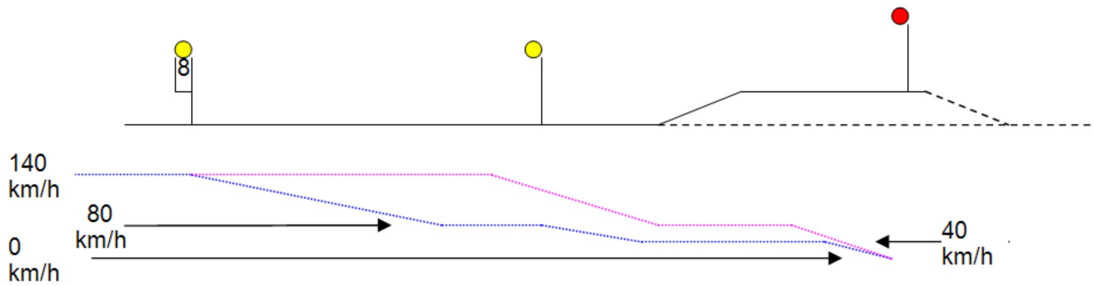
Introduction

Ommen is a small station the north-east-part of the Netherlands, along the regional line Zwolle-Emmen. One might think that a better performance with ETCS is only a solution for very busy lines in city areas. This case will show that also performance on single-track-lines can be improved strongly by using ETCS cab signalling.

This case also stresses many other situations where the Dutch safety principles, the current NS54 trackside signalling system and the national automatic train protection system “ATB” show their restrictive character towards speed. The same applies for both safety and performance problems with level crossings located nearby stations. So the Ommen-case is not only relevant for regional lines, but contains issues and solutions that can be implemented all over the network, including larger stations like Gouda.

Approach Ommen from direction Dalfsen

The main reason of the problem that occurs here, is that the trackside signals are installed on standard breaking distance (from Vmax to standstill), but the same signals must also indicate a restricted speed of 80 km/u because of a switch in diverting position. The consequence is that both the yellow-8 speed-restriction-aspect (to break from 140 to 80 km/h) and the yellow-aspect (to break from 80 to 40/0 km/h) force the train driver to start breaking far to early, with significant time loss as a consequence. In the drawing below the signalling and immediate-breaking-problem is elaborated.



Analysis

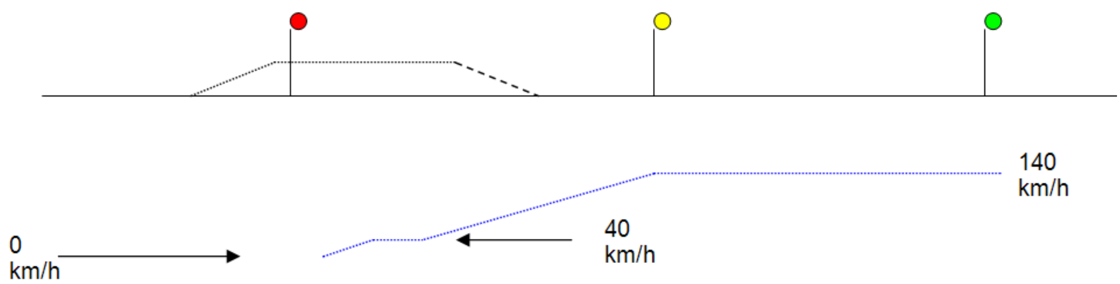
- The blue line in the speed-distance diagram clearly shows the immediate start of breaking after passing the yellow-eight- and the yellow-aspect. As a consequence the train drives too slow for long distances and looses time.
- The exact time depends on the exact deceleration when the breaks are in the minimum ATB-brake-criterion, but generally spoken a time loss of more than one minute can be expected.

Description using speed-distance-cab signalling-principles

- When using a modern cab signalling system like ETCS, the train does not need yellow trackside signals anymore, because the onboard cab signalling equipment will inform the driver when the train should be decelerated.
- As a consequence, the train is not hindered anymore by yellow signals forcing to break too early.
- The purple line in the speed-distance diagram shows that the train can continue its top speed of 140 km/h until it reaches the real breaking curve for the real position of the switch, instead of a worst-case-braking curve based on the position of the entry signal. The second breaking does not start at the former position of the entry signal, but when the train reaches the real breaking curve for the real end of the route (= end of the platform).
- Technology: can be realised with most technologies for cab signalling (ATB-NG, LZB, TBL2, Euro-ATB and ETCS-L1/2), but Euro-based solutions are highly preferable for interoperability and legislation reasons

Approach Ommen from direction Emmen – Mariënberg with red exit signal

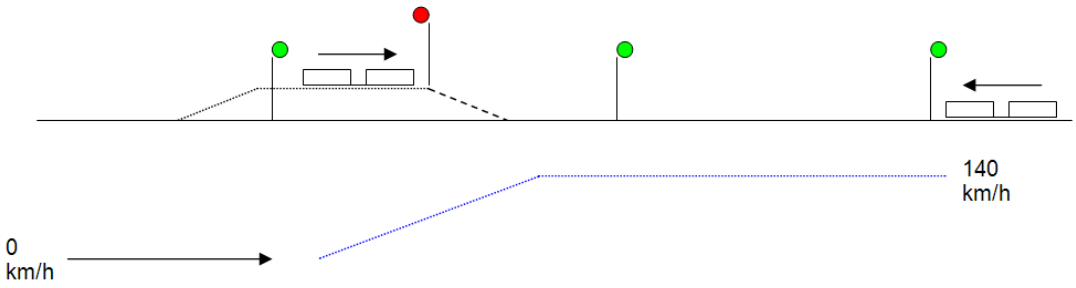
The situation in the drawing below is less problematic compared to the situation in the opposite driving direction, because there is no diverting switch. Therefore the approach signal shows green. Only the entry signals shows yellow, which forces the train to start braking at that position. As a consequence the damage towards speed- and time-performance is less, but still too big to be able to run a stable train service between the crossing stations Nieuw Amsterdam and Ommen.



Approach Ommen from direction Emmen – Mariënberg with green entry and exit signal

This capacity problem has been solved in a remarkable way: in the timetable the train from Zwolle is scheduled in such a way that this train is always earlier in Ommen[167], so the traffic control centre is able to set a continuous route through the station, as indicated in the second drawing. This is called a "hoog groen" ("high green") route.

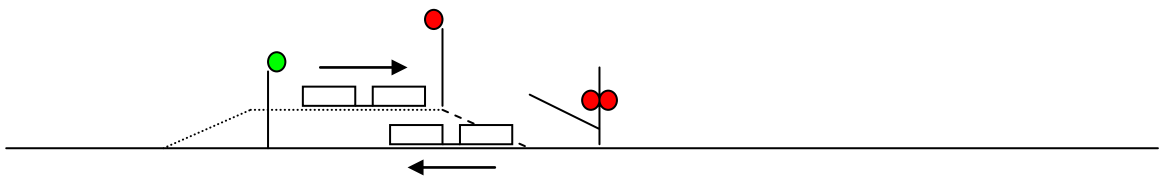
[167] this required additional margin, so the time loss in the opposite direction is even worse



At first sight, this seems to be a nice way to overcome the difficulties with the speed-restrictive-character of Dutch trackside signalling and ATP. But there is a serious drawback: there is also a level crossing at the west-side of the station. When traffic management in Zwolle sets a continuous route through the station Ommen, the level crossing is activated too early, and the level crossing will be closed unnecessary for almost 3 minutes. This is not a busy crossing and is only used by bikers, pedestrians and forest workers. However, closed level crossings without trains passing, might result in people crossing the track illegally, causing a safety risk.

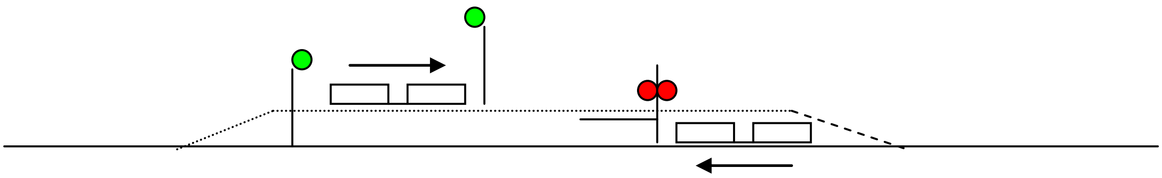
Leaving Ommen towards Mariënberg-Emmen – another delaying level crossing issue

In the drawing below the last regular situation in Ommen is depicted: the train from Emmen passes the station main road level crossing at the east-side, and enters the station. The train in the opposite direction is already waiting for some minutes to leave. At that moment the level crossing nearby the station opens. After a couple of seconds, the traffic control computer in Zwolle enters the new route, the switch changes towards the diverting position, the level crossing bells restart ringing, the wayside traffic – that just started moving – comes to a halt again, and the level crossing barriers move downwards.



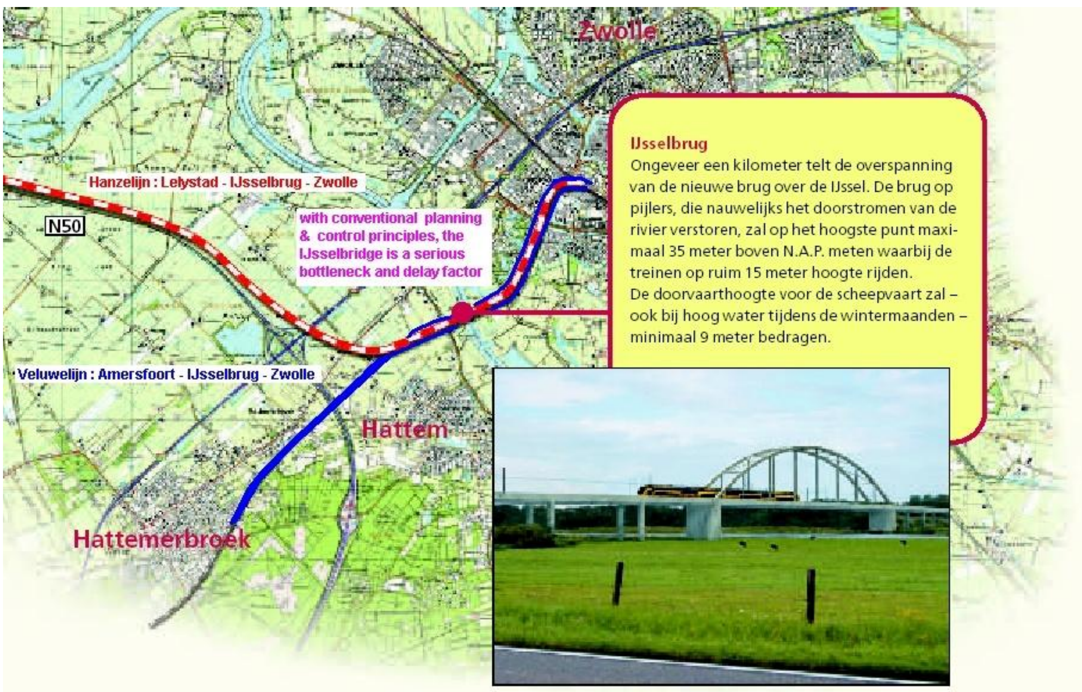
At that moment, the exit signal in the direction Mariënberg also goes to green. But then we are faced with the same problem as in Amersfoort and Den Haag HS: the train still cannot leave the station. First the door-closing-procedure has to be performed. It is not allowed to start the door-closing-procedure while the exit signal is not yet in a safe position. This has a safety background: the chance that both conductor and train driver overlook a red signal is significantly lower compared to a mistake by one of them. But if an advanced failsafe train protection technology like ATB-NG or ETCS is used, it is simple impossible to leave the station if no route is set: the train will initiate an emergency break immediately.

So if the train conductor is adaptively informed about the right moment to start the door-closing-procedure, for example by a white-flashing platform-signal, and the safety has been guaranteed by an advanced failsafe train protection technology like ATB-NG, Euro-ATB or ETCS, the level-crossing can be kept closed and the train towards Mariënberg can leave almost immediately after the train from the opposite direction comes in. This saves valuable time for both railway and road traffic, and significantly improves train punctuality, especially on regional single-track-lines. The positive effects for train and road traffic can be further improved when the double-track is extended beyond the level crossing.



Zwolle IJsselbridge: cabsignalling, short headway and Dynamic Slot Allocation

Source: PTADC



Problem description:

- In december 2012 the new “Hanzelijn” railway connection between Lelystad and Zwolle is opened
- Intercity-trains from the existing Veluwelijn and the new Hanzelijn have to share tracks on the two-track-bottleneck between IJsselbridge Junction and the station Zwolle

- Zwolle station is the railway gateway to the northern part of The Netherlands, and forms a main passengers transportation hub with lots of connecting services; therefore perfect interconnections in Zwolle station are essential for national attainability
- As a consequence of the very important interconnection at Zwolle, both Intercity-services must run in very close sequence through this bottleneck
- Current control technology and planning principles force a headway of 3 minutes through the bottleneck; the same headway applies for the bottleneck at the north side of Zwolle, between Zwolle and Meppel
- The 2x3=6 minutes headway, combined with 2 minutes interconnection time in Zwolle, results in a travel time loss for one of the Intercity-services of eight minutes, which is a serious economic loss

Classic solution:

- A four- or three-track IJsselbridge including connecting tracks towards Zwolle could save 3 minutes headway
- Four tracks from Zwolle to Meppel (28 km) could save also the other 3 minutes of headway.
- During Hanzeline project preparation, it was assumed that modern signalling & control would be available and used, therefore a two-track-IJsselbridge was considered to be sufficient. Four tracks towards Meppel has never been considered (clearly not cost-effective)

The deeper technical and procedural issues behind:

- The background reason of the three minutes headway and the resulting time loss has to do with the fact that historically trains could only be controlled effectively, efficiently and safely by using a robust timetable planning, in which the trains were separated in time by at least 3 to 5 minutes. Only in this way railway companies could arrange, with an acceptable probability, that trains would not hinder each other. Hindrance between trains results in significant time loss, punctuality and connecting problems, energy waste and even safety risks, especially in the old times with limited safety technology and slow breaking and very slow re-accelerating steam trains.

Solution for Zwolle station headway time loss problem

- With modern 21'th century communication & control technology expensive time and track space margins avoid hindrance can be reduced. Conflicts can be managed nowadays much more efficient by using minimal technical headways and dynamic control technology. Two or more trains are simply scheduled on the same passing time, and a dynamic control system finds out which one will run first and which one will be next.
- This principle of Dynamic Slot Allocation (which is common in airport / flight scheduling and can be seen as a Just-In-Time-management-method applied to traffic management) has already been introduced by ProRail around Schiphol railway station. In this way ProRail could create additional train capacity and avoid an extremely expensive and practically almost impossible physical extension of the underground Schiphol railway station and connecting tunnels

- The same basic principle of Dynamic Slot Allocation at Schiphol can also be used to reduce the costly headway time loss around Zwolle station from 6 to less than 2 minutes
- This requires a combination of Dynamic Slot Allocation with very accurate train position and speed monitoring, continuous data communication, smart traffic management, dynamic speed / traction advice generation ("Integrated Green Wave"-concept) and last-but-not-least an extremely short technical headway through the bottleneck.
- ERTMS Level 2 or 3 train control gives a good technical solution for this application, but even with short-distance blocks, accompanying trackside signalling and simple ICT-based tools like "RouteLint" or ERTMS-components, satisfying results can already be achieved. So the concept could start with a more pragmatic approach using trackside signalling, and could be further improved later on when ERTMS-equipment is available in all trains

Other cases that can be directly compared with Zwolle

- There are many other capacity bottlenecks or headway time loss issues in the Dutch railway network that also can highly benefit from this solution. Some examples:
  - local train Den Haag – Gouda – Woerden – Utrecht with prolonged waiting time in Gouda Goverwelle: this local train service could be made 4 minutes faster when Dynamic Slot Allocation - and Short Headway - control principles are used on the two-track-bottleneck between Gouda Goverwelle and Woerden
  - future capacity, congestion and energy / time loss / punctuality problems on the (already) four-track line between Boxtel and Eindhoven, when both cargo and Intercity traffic is further intensified and the Intercity maximum speed is increased towards 160 km/h. In this situation the intercity services from Tilburg and 's Hertogenbosch could share one track in between and use Dynamic Slot Allocation / Short Headway / Green Wave - control principles for a fast and delay-free traffic flow. The second track can then be used for local train services and cargo.

Lötschberg Basetunnel Switzerland: ETCS level 2 "Green Wave" control

The best proof of the fact that ETCS is already suitable for better railway utilisation and performance improvement is the Lötschberg Basetunnel case, where standard interoperable ETCS Level 2 components from different vendors are communicating with "commercial of the shelf" ICT solutions, and together form an intelligent "Green Wave" control application that guides extremely dense rail traffic flows in a safe, efficient and energy-saving way. The Lötschberg Basetunnel case clearly proves that better-utilisation-applications for Dutch real-life cases - like the Zwolle-bottleneck and may other cases - can be built and used today.

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