ETCS Hybrid Level 3: A Simulation-based Impact Assessment for the Dutch Railway Network

Joost Jansen, MSc, Delft University of Technology
Egidio Quaglietta, MSc PhD MIRSE, Delft University of Technology
Maarten Bartholomeus, MSc, ProRail
Alwin Pot, MSc, ProRail
Rob Goverde, MSc PDEng PhD FIRSE, Delft University of Technology

SUMMARY

Block signalling and Automatic Train Protection (ATP) are essential parts of railway signalling systems. In the Netherlands, the block signalling system NS'54 and ATP-system ATB-EG are installed on most mainline corridors. Railway capacity with these legacy systems is almost fully used while demand grows. Solutions are required to accommodate the railway demand increase forecasted for the next decade.

The European Rail Traffic Management System (ERTMS) and the European Train Control System (ETCS) offer benefits in the form of interoperability, increased safety, speed, capacity and reliability over legacy systems. ETCS Hybrid Level 3 is an integrated cab-signalling and ATP system that combines train position information, train integrity monitoring and trackside train detection. Compared to legacy systems and ETCS Level 2 it offers more railway capacity while reducing trackside train detection equipment.

This paper shows that the implementation of ETCS Hybrid Level 3 can significantly drop infrastructure occupation and capacity consumption with respect to legacy signalling. Also, the amount of trackside train detection can be reduced, resulting in an overall higher system reliability.

1 INTRODUCTION

In 2014, the Dutch government decided on the implementation of ETCS Level 2 [1] to renew the legacy signalling systems, enhance operation safety, and add further capacity, as a result of a European commitment including cross-country interoperability. ETCS Level 2 has been planned to be deployed over several mainline corridors by 2030. ETCS Level 3 technology allows transitioning to moving-block train operations to enable higher capacity while fully eliminating trackside train detection. However, this puts a high demand on on-board devices to monitor position and integrity of all trains in all modes of operation. The lack of train position information when operating without radio communication (e.g. shunting or degraded situations) will reduce availability drastically. Also no practical solution currently exists to provide onboard Train Integrity Monitoring (TIM) for all types of trains (e.g. freight trains with variable compositions), which solely relies on train position reporting in an ETCS Level 3 setup.

To overcome these issues, a new concept has been developed: ETCS Hybrid Level 3 [2]. This concept combines train position information, train integrity confirmation and trackside train detection. It mitigates operational risks in degraded scenarios and allows for fast and robust system recovery.

Section 2 introduces the state of the art on Dutch signalling and drivers for the migration to ETCS. In section 3 the principles of ETCS Hybrid Level 3 are presented. Section 4 introduces the methodology of this study, the results are presented in section 5. This results in the conclusions which are included in section 6.

2 STATE OF THE ART ON SIGNALLING IN THE NETHERLANDS

2.1 Dutch railway signalling systems

The Dutch systems responsible for ensuring safety of train operations on the main part of the national network are the block signalling system NS'54, the ATP system ATB-EG and track-free detection based on track circuits. NS'54 is a progressive speed signalling system based on a two-block three-aspect signalling system [3]. Automatische TreinBeïnvloeding Eerste Generatie (ATB-EG) is a continuous automatic train protection system using coded track circuits with brake application check and supervision of a limited number of speeds [4]. Track occupation monitoring is performed via track circuits based on electrically insulated track sections. [5]

2.2 Migration to ETCS

The Dutch legacy block signalling system NS'54 in combination with the ATP-system ATB-EG on the main lines is functioning well, but it has some drawbacks. The railway capacity of the Dutch network with the legacy systems is almost fully used. Solutions are required to accommodate future demand growth [6]. Both NS'54 and ATB-EG have been designed over 60 years ago with technology of that time. Components are obsolete and will have to be replaced in the future. The ATB-EG functionality for speed supervision is limited to only five speed steps (40, 60, 80, 130 and 140 km/h) and full brake supervision is lacking.

Four main drivers for the replacement of the legacy systems can be identified: i) the need of additional railway capacity, ii) the renewal of the existing signalling systems, iii) improvements of the safety functionality of the systems, and iv) the commitment to European policies for interoperable signalling [7].

ETCS is proposed to be the new standard European cab signalling system. ETCS could provide interoperability, enhanced safety, increased operational train speeds, increased railway capacity and improved system reliability over the legacy NS'54/ATB-EG system. The Dutch government decided therefore to replace legacy systems on some mainlines with ETCS Level 2 by 2030.

To fully benefit from ETCS Level 2 [8], corridors have to be divided into shorter block sections, requiring a substantial amount of trackside equipment including train detection. A large amount of trackside train detection and other trackside equipment will negatively impact installation and maintenance costs.

The concept of ETCS Level 3 supports moving-block or virtual-block train operations allowing a higher capacity while completely eliminating trackside train detection. Nevertheless, several challenges still need to be solved by the railway industry before such a technology can be operational [9], namely:

- An on-board train integrity monitoring device needs to be equipped that works for all types of operating trains independently from their composition and rolling stock characteristics;
- The trackside Radio Block Centre (RBC) needs to accurately know the position of all trains at all times to ensure safety. The trackside is blind for non-communicating but moving trains;
- In case of an (un)intended communication failure the knowledge of train positions and train integrity may be lost completely. This requires cumbersome operational requirements to recover from failures;
- A very high accuracy of the position reports is required to prevent locks of critical infrastructure elements.

3 ETCS HYBRID LEVEL 3

To overcome the issues of ETCS Level 3, a hybrid solution comes into play: combining the ETCS Level 3 integer train position information with limited trackside train detection. This principle fits the valid ERTMS procedures and mitigates operational risks.

Communication between track and train relies on the GSM-R connection, as in ETCS Level 2. The system principles with onboard TIM (Train Integrity Monitoring), trackside train detection and GSM-R radio communication between track and train are presented in Figure 1.

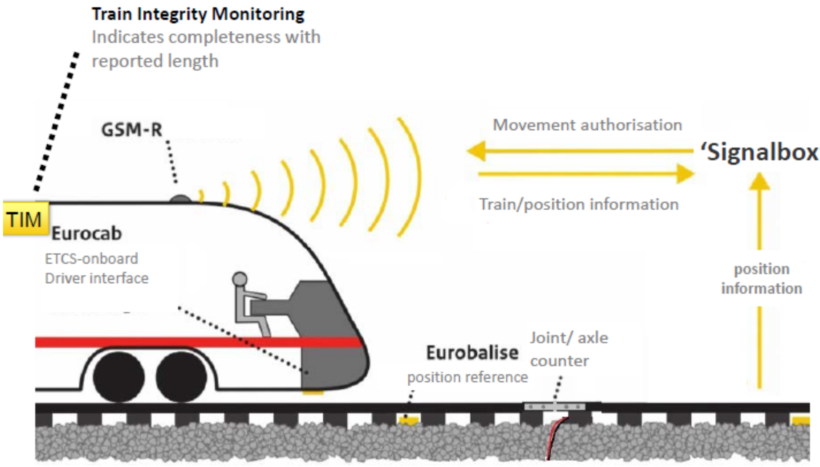


Figure 1: ETCS Hybrid Level 3 system principle

This study uses the ETCS Hybrid Level 3 concept based on virtual subsections (VSS) and reduced trackside train detection (TTD). The virtual subsections are a software implementation configured in the trackside system and divide the physical detection blocks into smaller block sections. Section borders are physically marked by trackside Stop Marker Boards (SMB). Position reports from the proven complete trains are used to authorise following trains at short distances, with the minimum headway being the size of the virtual subsections. If a train follows another train that is not equipped with onboard TIM, safe operations are provided by the trackside train detection. Figure 2 presents a train following scenario for all TIM-equipped trains.

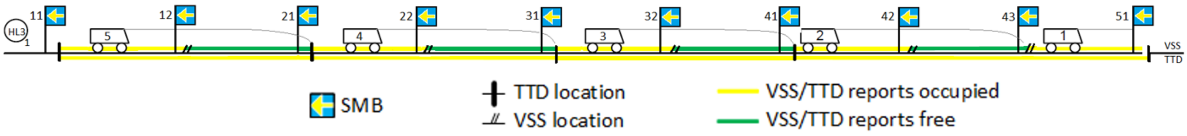


Figure 2: Train following, ETCS Hybrid Level 3

Real-life tests of ETCS Level 3 and Hybrid Level 3 have been conducted over the past years in the Netherlands, United Kingdom and Germany. Despite these pilot tests, the effects of ETCS Hybrid Level 3 on railway capacity and reliability for the Dutch railway network are not yet fully quantified. To this end, this paper performs a detailed investigation to quantify capacity and benefits/limitations of ETCS Hybrid Level 3 with respect to ETCS Level 2 and legacy signalling systems in the Netherlands.

4 METHODOLOGY

To evaluate the performance of ETCS Hybrid Level 3 a detailed simulation study has been carried out. A conceptual model of ETCS Hybrid Level 3 principles has been implemented in the microscopic railway traffic simulation tool RailSys V11 [10]. ETCS Hybrid Level 3 has been incorporated in RailSys by creating dual-signalling with different block-release procedures for TIM-equipped trains and non-TIM-equipped. Standard types of rolling stock have been modelled taking into account mechanical/physical characteristics (i.e. length, mass, number of cars, tractive effort-speed curve) that are relevant to the corridor [11]. The rolling stock for intercity trains is VIRM-VI, the regional trains (sprinters) use an SLT-VI while the freight trains operate a BR186 TRAXX + wagons of 550 m and 2000 tonne. The analysed 2019-timetable includes 6 hourly intercities, 6 sprinters and 2 freight trains.

Simulation outputs provide running times and blocking times [12], the latter describing the time a given track section is exclusively allocated to a given train from the track setup to the track release. Infrastructure occupation of a corridor is then obtained by compressing blocking time diagrams of all trains scheduled in one hour according to the UIC 406 Leaflet timetable compression method [13]. For mixed-traffic railway lines the UIC recommends a maximum infrastructure occupation of 75% to provide a stable and robust timetable, able to effectively mitigate daily service perturbations. The capacity consumption of the corridor is instead obtained by adding a given buffer time between each train in the compressed timetable. A capacity consumption above 100% means that the proposed timetable is unfeasible to be operated within the reference time unless train paths or buffer times are adjusted.

The impact of changes in the trackside equipment is based on the expected track unavailability, expressed in the number of yearly Train Depleting Irregularities (TDIs). A TDI is a trackside irregularity that leads to a delay of at least 3 minutes for at least 1 train. It is an indicator used by the Dutch railway infrastructure manager ProRail to classify infrastructure unavailability.

The TDIs can be divided in four infrastructure categories and five classes of originating causes. The infrastructure categories are ‘rail systems’ (tracks, junctions, civil constructions and power supply), ‘train protection systems’ (signalling, ATP trackside, trackside train detection), ‘ICT’ (information and communication technologies) and ‘unknown’ for other breakdown structures. The originating causes of a fault are instead divided into ‘technical failures’, ‘process errors’, ‘third parties’ (where the responsible is an actor other than the infrastructure manager), ‘weather’ and ‘unknown’ (used when no clear explanation can be found). Given that this study is about signalling systems, the analysis focuses exclusively on the infrastructure asset category ‘train protection systems’. For such an asset category a prediction of future yearly TDIs is here made based on data collected on component reliability during the year 2018 [14].

5 CASE STUDY

5.1 Infrastructure variants

To assess the effects of ETCS Hybrid Level 3 on capacity and system reliability, five infrastructure variants have been developed and tested (Figure 3). Technical features of each variant are described as follows:

Variant 1. **NS’54/ATB-EG**. This infrastructure variant leaves the existing infrastructure, signals and train protection system in place. It models the behaviour of the legacy system as is, as a benchmark for the ETCS signalling implementations.

Variant 2. **ETCS Level 2**. This infrastructure variant replaces NS’54 signals with ETCS Stop Marker Boards (SMBs) and the ATB-EG block sections with ETCS Level 2 equivalents. This variant is a simplification of the implementation of ETCS Level 2, without modification and optimization of the block layout. The existing trackside train detection is maintained. All trains release block sections based on the trackside train detection. The speed profile is adjusted to match the infrastructure restrictions instead of the block restrictions, which slightly reduces the minimum technical running times of all trains.

Variant 3. **ETCS Hybrid Level 3 with intermediate virtual subsections**. The ETCS Level 2 block sections are divided into smaller virtual subsections of around 500 m each. Trains equipped with a TIM release these blocks at the end of (virtual) blocks and at trackside train detection elements. Trains without TIM instead only release trackside train detection elements. All original trackside train detection is maintained.

Variant 4. **ETCS Hybrid Level 3 with small virtual subsections**. The infrastructure is further optimized by reducing the length of virtual subsections up to around lengths of 100 m at critical locations such as junctions and stations. The size of virtual subsections is related to the scheduled train speeds with larger blocks at higher speeds. All existing trackside train detection is maintained in this infrastructural variant.

Variant 5. **ETCS Hybrid Level 3 with small virtual subsections & reduced trackside train detection**. This variant relies on the same virtual sub-sectioning of Variant 4 and reduces trackside train detection to the bare minimum. All existing trackside train detection is removed and replaced by detection only at critical locations, such as at switches and level crossings so to ensure safe operations for all train types.

The track infrastructure of the Dutch railway corridor Utrecht – Den Bosch has been modelled according to the 2019 track layout and the valid Engineering Rules to test the impact of ETCS Hybrid Level 3 and compare the results with ETCS Level 2 and NS’54/ATB-EG.

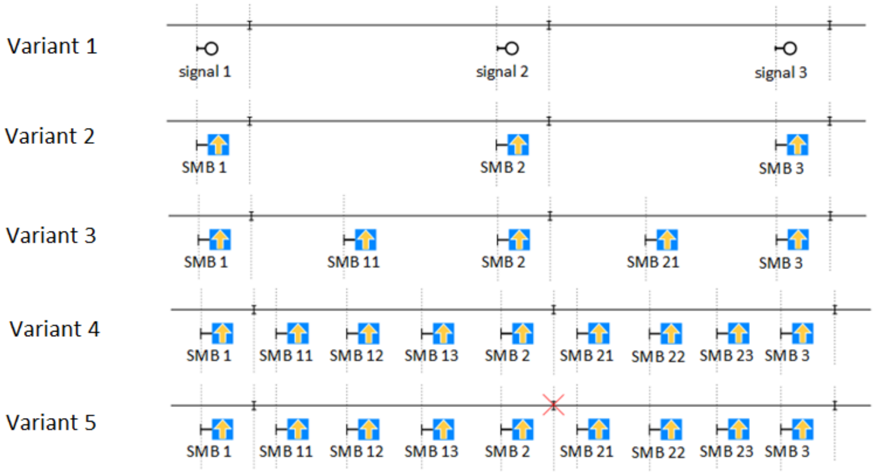


Figure 3: Five investigated infrastructure variants

5.2 ETCS braking model

Compared to NS'54/ATB-EG, ETCS offers train dependent, block independent, route and speed dependent braking. This allows the train to start braking not earlier than required for the specific track/train combination, resulting in reduced minimum running times.

The ETCS Baseline 3 specification harmonises the ETCS braking curve functionality. It unifies the speed, distance and braking control in the brake model. This harmonisation results in predictable train behaviour and braking characteristics, which allows for a clear division of the safety margins into trackside margins (to be decided on by the infrastructure manager) and train-dependent margins.

Trains with fixed length or a limited number of predefined possible compositions use the gamma-model. The infrastructure manager is allowed to set a confidence level to the nominal brake deceleration, which is included in the Integrated Correction Factor K_dry. The required Dutch confidence level is 99,99% or Confidence Level (CL) 4.

Trains with variable compositions use instead the conversion (lambda) braking model. The infrastructure manager can change the safe brake deceleration of these trains by modifying the Integrated Correction Factors Kr_int (length dependent correction factor), Kv_int (speed dependent correction factor) and Kt_int (correction of the brake build-up time, i.e. the time needed for the brakes to be applied to the entire trainset).

In addition to the Emergency Brake Deceleration (EBD) curves and the emergency brake intervention (EBI) limit, ERTMS includes multiple guidance curves. Service Brake Deceleration is not included in the Dutch National Values. Two seconds prior to reaching the EBI-limit the system re-invites the driver to apply the brakes. Four seconds prior to reaching the EBI-limit the system returns the Permitted (P) curve, which guides the driver along a safe and comfortable deceleration. Nine seconds prior to the P-curve the system returns the Indication (I) curve, which indicates to the driver that the movement authority is about to end. For capacity assessment, the I-curve is used, to prevent the driver from being confronted with an intervention.

5.3 Blocking times

The brake model and the Integrated Correction Factors have a direct impact on the braking distance of the train and thereby on the blocking times of the individual (virtual) block sections. The difference in infrastructure occupation between trains with and without onboard TIM becomes clear in ETCS Hybrid Level 3 (see Figure 4). Trains equipped with onboard TIM occupy and clear the infrastructure based on position reports, releasing the infrastructure on a regular basis at each of the virtual subsections. Trains without onboard TIM have a similar occupation process, but the infrastructure release is dependent on the trackside train detection. This results in larger block release times after a non-TIM-equipped train has passed.

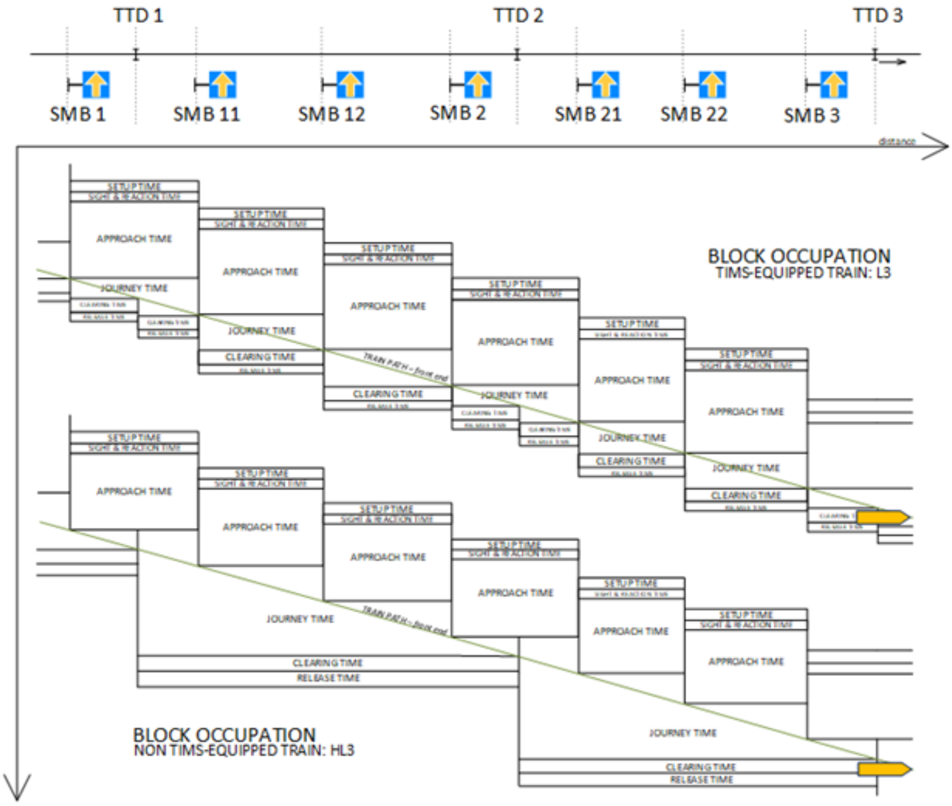


Figure 4: Block occupation for TIM-equipped trains and non-TIM-equipped trains

5.4 Operational scenarios

Several operational scenarios have been analysed in this study which consider different configurations of the ETCS braking curve parameters as well as disturbances to nominal train service due to delays and component faults. For each operational scenario the five infrastructure variants have been compared in terms of running times, infrastructure occupation, capacity consumption as well as the time to recover from a perturbation.

The first operational scenario assumes nominal undisturbed train service with default Integrated Correction Factors of the ETCS braking curves. The second operational scenario instead refers to different values of the Integrated Correction factors to take into account for best- and worse-case conditions and a higher and lower confidence in the braking deceleration of the rolling stock. The values that have been analysed are specifically:

i) The default K_dry value of 0,88 , based on CL4 and the best-case scenario for gamma trains;

ii) K_dry of 0,80 (CL4, worst-case scenario) and 0,70 (CL8, worst-case scenario);

iii) The default Kr_int, Kv_int and Kt_int values of 1, 0,9 and 1 for lambda trains, respectively;

iv) Kr_int of 0,9 for all train lengths;

v) Kv_int of 0,76 and 1 for all train speeds;

vi) Kt_int of 0,80 and 1,30 for all train lengths.

The third operational scenario assumes a delay of 30 minute due to a train fault to understand the ability to recover from perturbations of the five infrastructure variants. A fourth operational scenario focuses instead on increasing the number of operating trains in the hourly timetable so to identify which of the infrastructure variants could effectively allow accommodating a denser train service serving the forecasted railway demand increase. The five infrastructure variants are then compared in terms of asset reliability based on TDI data collected in the year 2018 for the Dutch network.

Simulation experiments have been realised for the 48 km-long railway corridor between Utrecht and Den Bosch considering the timetable for the year 2019, including 6 hourly intercity trains, 6 sprinters and 2 freight trains. The simulation results for each operational scenario are reported in the next sections.

5.5 Results

5.5.1 Undisturbed service and default braking curve correction factors

Results for the operational scenario considering nominal train service and default values of the Integrated Correction Factors are provided for each infrastructure variant in Table 1.

Table 1: Infrastructure occupation and capacity consumption for the five infrastructure variants

		Infrastructure occupation	**Capacity consumption**
NS'54/ATB-EG		84,0%	104,0%
ETCS L2		74,3%	90,9%
ETCS HL3	500m virtual subsections, existing TTD	70,4%	87,2%
ETCS HL3	Virtual subsections up to 100m, existing TTD	66,7%	82,4%
ETCS HL3	Virtual subsections up to 100m, reduced TTD	71,7%	88,8%

The legacy system NS'54/ATB-EG results in an infrastructure occupation of 84% which indicates timetable instability according to the UIC which recommends a maximum occupation of 75%. The corresponding capacity consumption exceeds 100% which means that the timetable in unfeasible and some adjustments are required (e.g. reduction of buffer times, removal of train paths) to avoid conflicting train movements. The adoption of ETCS Level 2 results in a 10% decrease of capacity consumption, Hybrid Level 3 with subsections of 500 m in 13,5%, while reducing the size of the virtual subsections decreases the infrastructure occupation by another 7%. Using the same small virtual subsections and simultaneously reducing trackside train detection to the minimum (ETCS Hybrid Level 3 with 100 m subsections and reduced TTD) results in almost 3% capacity benefits over ETCS Level 2 and over 12% compared to the legacy system.

5.5.2 Sensitivity of integrated correction factors of ETCS braking curves

A sensitivity analysis of integrated correction factors has been carried out to identify their influence on the braking behaviour and hence on running times of individual trains. Results of this analysis are reported in Table 2. In general, the minimum running times of the individual trains vary only little. The deviation of minimum running times of gamma trains by varying K_dry is limited to 3 seconds per train when changing K_dry to 0,70. Varying the factors Kr_int, Kv_int and Kt_int for lambda trains results in slightly larger variations in the minimum running times. The biggest impact is found when varying the correction factor on brake build-up time. In this case the minimum running times of lambda trains deviate by up to 15 seconds when compared to the default value of 1,0.

The impact of these changes on the infrastructure occupation is limited as well. Changing the integrated correction factor K_dry for gamma trains results in a deviation of the infrastructure occupation of at most 0,5% when compared to the default value of 0,88. The maximum deviation occurs when changing the factor K_dry to match the highest confidence level and the worst-case scenario for the braking performance.

Table 2: Infrastructure occupation for different values of Integrated Correction Factor K_dry (gamma trains)

		K_dry 0,88	**K_dry 0,80**	**K_dry 0,70**
ETCS L2		74,3%	74,4%	74,5%
ETCS HL3	500m virtual subsections, existing TTD	70,4%	70,4%	70,7%
ETCS HL3	Virtual subsections up to 100m, existing TTD	66,7%	66,9%	67,1%
ETCS HL3	Virtual subsections up to 100m, reduced TTD	71,7%	71,9%	72,2%

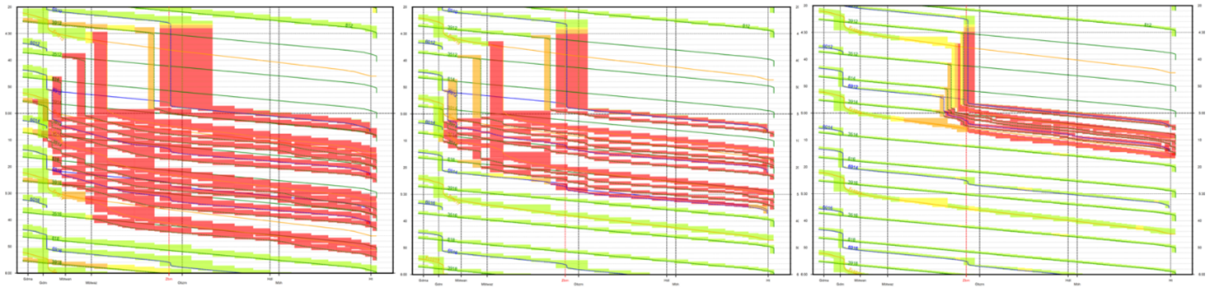
Changing the integrated correction factors for lambda trains results in slightly bigger variations in the infrastructure occupation, as reported in Table 3. The train length dependent correction factor Kr_int and the train speed dependent correction factor Kv_int result in deviations of the infrastructure occupations by 0,9% compared to the default values. As with the minimum running times, changing the brake build-up correction factor Kt_int has the biggest impact on infrastructure occupation.

Table 3: Infrastructure occupation for different values of Integrated Correction Factor Kt_int (lambda trains)

		Kt_int 0,82	**Kt_int 1,0**	**Kt_int 1,30**
ETCS L2		73,5%	74,3%	74,5%
ETCS HL3	500m virtual subsections, existing TTD	69,8%	70,4%	70,9%
ETCS HL3	Virtual subsections up to 100m, existing TTD	66,5%	66,7%	67,2%
ETCS HL3	Virtual subsections up to 100m, reduced TTD	71,4%	71,7%	72,6%

5.5.3 Delay propagation of a 30-minute perturbation

To evaluate the different infrastructure variants with respect to robustness to perturbations, a 30-minute delay has been considered in the simulation. This study does not consider re-routing and trains wait for their route to come available. Results are illustrated in Figure 5. The variant of ETCS Hybrid Level 3 with short subsections (Variant 4) can recover the perturbation 42% faster than the legacy system, while reducing total delays by almost 40%. ETCS Level 2 also offers an improved performance compared to the legacy system, but its benefits are limited when compared to ETCS Hybrid Level 3 which has the advantage of short-following of trains under perturbed operations. For NS'54/ATB-EG the queue of affected trains does head back quite far on the corridor, taking over 3 hours to recover from the perturbation due to the large headways, while with ETCS Hybrid Level 3 the queue is limited in length as the given headways are much smaller.



NS'54/ATB-EG

ERTMS/ETCS L2

ERTMS/ETCS HL3

Figure 5: 30-minute perturbation, NS'54/ATB-EG, ETCS Level 2 and ETCS Hybrid Level 3

5.5.4 Train service increase

Overall system performances of ETCS Hybrid Level 3 have been compared to ETCS Level 2 in terms of number of trains, average speed, stability and the heterogeneity (traffic mix) that the two signalling systems can allow when deployed. Results have been reported in a diamond diagram in Figure 6. The variant of ETCS Hybrid Level 3 with small virtual subsections in combination with the position report-based block release (Variant 4) reduces headways by 50 to 75 seconds per train when compared to the legacy system. Such capacity benefits of ETCS Hybrid Level 3 of up to 17% with respect to the legacy system do change the capacity balance of the system. Three scenarios are considered to be feasible: increasing the average train speed, increasing the train frequencies and increasing the timetable stability.

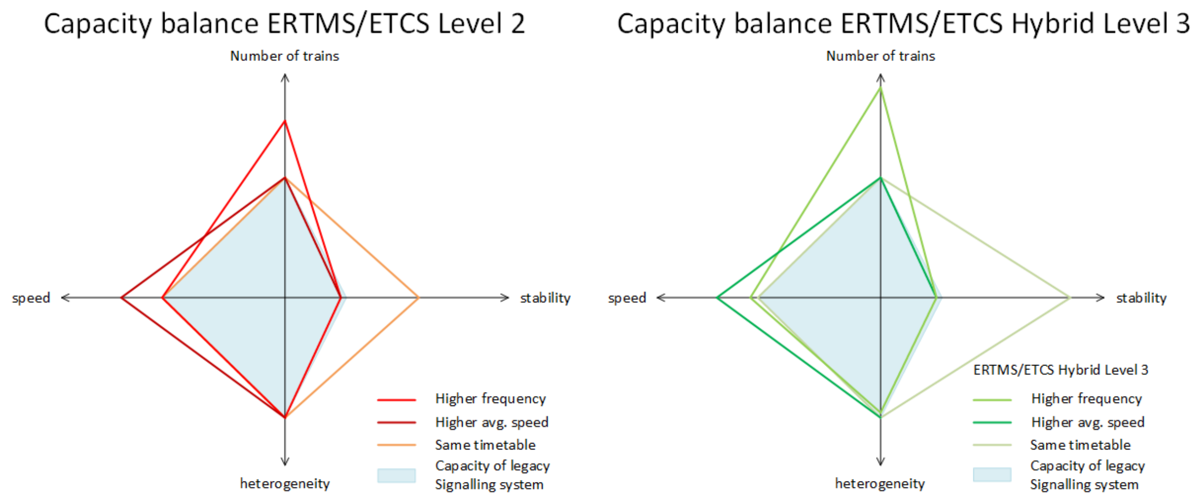


Figure 6: Capacity balance of ETCS Level 2 and ETCS Hybrid Level 3

In the light of expected future demand growth, two more hourly intercity trains (hence 8 ICs instead of the original 6) have been included in the timetable and determine the infrastructure occupation and the capacity consumption for ETCS Level 2 and the three ETCS Hybrid Level 3 variants. Results of this analysis are presented in Table 4. For three of the four scenarios the infrastructure occupation rates exceed the UIC recommendation of 75%, but all infrastructure occupation rates are decreased compared to the legacy signalling system with only 6 intercitiy trains per hour. The capacity consumption of three variants exceeds the 100% maximum indicating that timetable adjustments are required to make operations feasible.

Table 4: Infrastructure occupation and capacity consumption, 8 ICs/h

		Infrastructure occupation	**Capacity consumption**
ETCS L2		82,6%	105,9%
ETCS HL3	500m virtual subsections, existing TTD	77,6%	100,9%
ETCS HL3	Virtual subsections up to 100m, existing TTD	73,1%	96,4%
ETCS HL3	Virtual subsections up to 100m, reduced TTD	79,1%	102,4%

5.5.5 Asset reliability

In the year 2018, over 10.000 TDIs were registered, of which almost 2.100 were related to train protection systems. The causes of the TDIs in this category are completely different to the rest of the TDIs. Most of the irregularities in this category are caused by technical failures (66,8%) or process errors (11,8%), where the most frequent cause over all categories is originated by ‘third parties’ (54,2%).

TDIs for the category ‘train protection systems’ are reported in Figure 7. Most of the TDIs of that category are caused by broken equipment of the track circuits and the insulated joints. Signals are the other main cause of failures. From the breakdown it seems that the ETCS-equipment and axle counters are only rarely subject to irregularities, but the assets themselves are also less in amount. However, data show that ETCS equipment is almost 40% more reliable than legacy train protection devices. Replacing track circuits with axle counters could result in 50% less irregularities.

Figure 7: TDIs per asset per year (data of 2018), category 'train protection systems'

The relevant components of the category ‘train protection systems’ are predicted in terms of TDI for the five presented infrastructure variants considering current Dutch engineering rules.

First, a prediction is made with the existing trackside train detection in the form of track circuits. Second, the track circuits are replaced by axle counters. Each section is equipped with an axle counter on both ends, while a junction is equipped with a total of 3 axle counters, a crossover is equipped with a total of 12 axle counters and a level-crossing is equipped with a total of 4 axle counters. Third, a prediction is made for future TDIs when the trackside train detection is reduced to the minimum under ETCS Hybrid Level 3 (Variant 5). This is only possible when implementing axle counters as the section length increases beyond the maximum length that can be covered by a track circuit.

Outcomes of TDI predictions are provided in Figure 8. The legacy NS’54/ATB-EG with track circuits will cause almost 50 irregularities per year. ETCS implementation will slightly decrease the number of irregularities. It is worth noticing that the increase of virtual subsections in the different ETCS Hybrid Level 3 implementations will not change the unavailability by much. Indeed virtual subsections are a software solution that will cause only limited unavailability when compared to hardware components. Furthermore, replacing track circuits with axle counters causes a drop of almost 20% unavailability for each variant. When reducing the amount of trackside train detection to the minimum (Variant 5) and simultaneously transferring to axle counters, the number of Train Depleting Irregularities can drop by 40% per year when compared to the legacy system.

There is no general optimum in the exact amount of trackside train detection. The optimum depends on the characteristics of the corridor as well as the train traffic. Also, it is up to the infrastructure manager to decide on the required performance of the corridor, the balance of performances and possible track unavailability due to failing signalling and trackside train detection components.

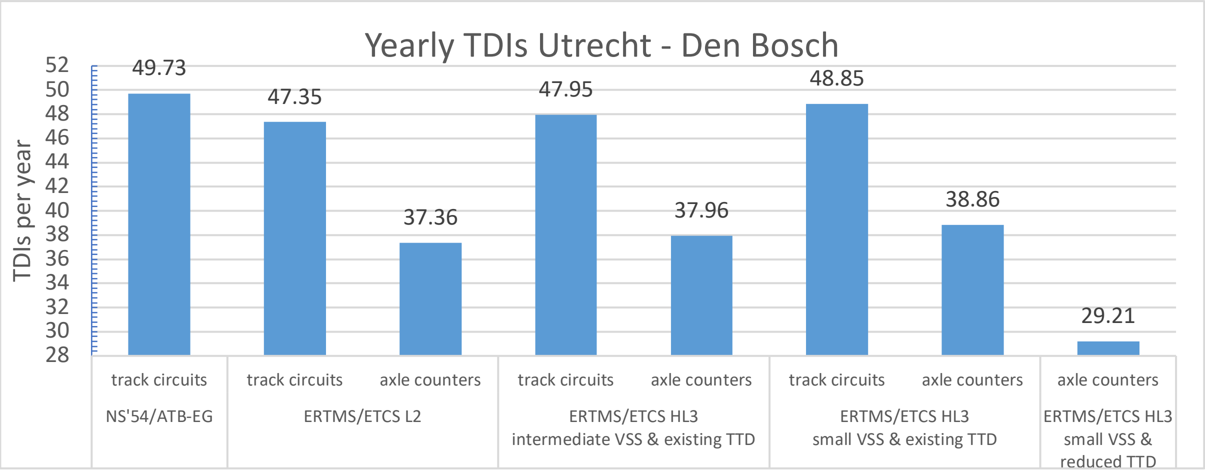


Figure 8: Prediction for future yearly TDIs in the category 'train protection systems', per infrastructure variant

6 CONCLUSIONS

ETCS Hybrid Level 3 is a new and promising signalling concept. By creating short blocks and using both the onboard Train Integrity Monitoring and the trackside train detection, ETCS Hybrid Level 3 delivers optimal performance and mitigates operational risks in degraded scenarios. The system allows for capacity benefits up to 17% compared to the legacy systems as well as possibilities for reduction of trackside equipment. This results in the possibility to increase train frequencies to meet future demand and increase track availability significantly. The balance between capacity and reduction of trackside equipment has to be made by the infrastructure manager network-specific, as the balance can differ from corridor to corridor.

7 REFERENCES

1. De staatssecretaris van Infrastructuur en Milieu. *Voorkeursbeslissing ERTMS en Railmap 3.0 / Nota Alternatieven*. Den Haag: Ministerie van Infrastructuur en Milieu, 2014.
2. Bartholomeus, M., Zweers, M. A recipe for a fast nationwide migration to robust ERTMS L3. *Signal+Draht* 105 9/2013: 43-48, 2013.
3. Middelraad, P. *Voorgeschiedenis, Onstaan en Evolutie van het NS-lichtseinstelsel*. Utrecht: NS Railinfrabeheer, 2000.
4. Fokke, C.L. *ATB Algemene informatie Deel 1*. Utrecht: Nederlandse Spoorwegen Opleiding & Vorming, 1985.
5. General Railway Signal. *Elements of Railway Signaling*. GRS, 1979.
6. Ministerie van Infrastructuur en Waterstaat, de twaalf provincies en de metropoolregio's Amsterdam (MRA) en Rotterdam-Den Haag (MRDH), de openbaar vervoersbedrijven NS en Federatie Mobiliteitsbedrijven Nederland en stadsvervoerders GVB, RET en HTM, en de infrabeheerder ProRail. *Contouren Toekomstbeeld OV 2040*. Den Haag: Ministerie van Infrastructuur en Waterstaat, 2019.
7. European Commission, Transport. *Infrastructure – TEN-t – Connecting Europe* [online]. https://ec.europa.eu/transport/themes/infrastructure_en [20-10-2018].
8. Ministerie van Infrastructuur en Milieu, ProRail, NS. *ERTMS Kennisboek versie V2.0.* Den Haag: Ministerie van Infrastructuur en Milieu, 2014.
9. Furness, N., van Houten, H., Arenas, L., Bartholomeus, M. ERTMS Level 3: the Game-Changer. *IRSE News* Issue 232: 2-9, 2017.
10. RMCon Rail Management Consultants. *RailSys Suite* [online]. https://www.rmcon.de/railsys-en/railsys-suite/ [20-10-2018]
11. Van der Velden, J., Stark, H. *ETCS Indicatieve gammawaarden VIRM, SLT*. Utrecht: ERTMS-programma, 2016.
12. Hansen, I. A., Pachl, J. *Railway Timetabling & Operations, 2nd edition.* Hamburg: Eurailpress, 2014.
13. Union internationale des chemins de fer. *UIC Leaflet 406: Capacity*, 2nd edition. UIC, 2013.
14. ProRail. *Dashboard Hinder – Storingen* [online]. https://dashboard.prorail.nl/ [06-04-2019].