Identification and Assessment of ETCS Level 3 Impediments

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SUMMARY

The objective of this paper is to provide an overview of the most significant impediments for the deployment of ETCS level 3. The Dutch railway network is used for a case study analysis. Eight main challenges are identified and studied through literature review and interviews with Dutch Railway experts.

Results of the assessment indicate that there are major and minor challenges for the realization of ETCS level 3. The minor challenges are expected to be overcome by defining fairly manageable operational procedures, the use of currently available technology and allocating adequate financial resources. While the major challenges, so called impediments, cannot be easily resolved at the moment due to technology limitations, complexity in operation and/ or financial risks.

The impediments include limited possibilities to increase capacity, integrity confirmation of yellow fleet and freight trains, limitations of GSM-R to support ETCS communication in busy railway stations and safe recovery from degraded operation modes.

Integrity confirmation of passenger trains, costs related to life cycle, taking / revoking possessions, autonomous operation of open line level crossings and realizing an optimal migration path towards ETCS level 3 are perceived as minor challenges.

The regional line between Groningen – Roodeschool is recommended as a corridor to execute an ETCS level 3 pilot, because the impact of the major impediments is less significant on this track. The pilot would help ETCS experts to define and verify optimal operational rules and design principles for a wider implementation.

1 INTRODUCTION

The Dutch railways expect to experience a significant increase in the number of passengers of 30 up to 45% in the upcoming decade, which would cause sever congestion by 2030. For the Netherlands, the opportunity to increase capacity by additional infrastructure is limited, therefore, other solutions, like modifications in the signalling system are being looked into. ETCS (European Train Control System) is one of the solutions which makes it possible to use the existing infrastructure more efficiently.

ETCS level 3 has been added in the Baseline 3 specification by ERA (European Rail Agency). In this application level, train data (location, speed, traveling directions, confirmation of integrity) is reported to the RBC (Radio Block Centre) and used by the interlocking to set a route. Since trackside detection equipment in ETCS level 3 is no longer needed for route controls, a moving block principle can be implemented, which makes it possible to reduce the headway between trains. It is expected that, like in automated metro systems, applying the moving block principle can significantly increase the number of trains and the capacity of a railway network.

A further increase in capacity and energy-optimised driving could be achieved by implementing ATO (Automatic Train Operation) over ETCS. Moreover, improvements in safety and reduction of trackside equipment costs are other benefits expected from ETCS level 3.

Nevertheless, in the Netherlands, it has been decided to gradually implement ETCS level 2, first in the rolling stock and then gradually on ProRail's network. Starting in 2026 seven corridors (340 out of 3,223 km) of the Dutch railway network will be equipped with to ETCS level 2 (Prorail, 2019). The remaining parts of the network will also be equipped with ETCS level 2 before 2050. (ERTMS, 2019)

The Dutch ERTMS (European Rail Traffic Management System) Programme indicated the strong preference for applying proven technology (level 2), and therefore, ETCS level 3 was not taken into account in the current rollout plans, as the technical solutions are only in development. Also train integrity concepts or operational scenarios for starting the system after a failure needs still to be decided.

ETCS level 2 as well as level 3, will contribute to the improvement of safety and the reduction of SPADs (Signal Passed at Danger) by continuously monitoring the speed of the train. This is a significant benefit compared to the ATB EG (Automatische treinbeïnvloeding Eerste Generatie) system, that is currently being used. However, ETCS level 2 might not fully meet the traffic demand needs due to the use of fixed blocks. Therefore, by 2030 the congestion challenge is not likely to be solved and additional benefits of ETCS level 3 might become more important.

Although ETCS level 3 appears to be the way to move forward in order to meet the future traffic needs, not only the Netherlands, but also other countries are hesitant to deploy this most advanced level of European signalling. For example, Switzerland, Norway, Austria and Belgium are planning to roll out ETCS level 1 and / or 2.

Why are railway operators and infrastructure managers not eager and enthusiastic to implement ETCS level 3? Are the state of the level 3 technology and recovery from degraded modes the only limiting factors? Are there any other operational, technical or financial barriers which impede the realization of level 3 or are they just having cold feet? If any barriers exist, should they be regarded major impediments or minor hinderances? And finally: Are any solutions available for these barriers at the moment?

The research presented in this paper aims at identifying and analysing the underlying barriers for the deployment of the ETCS level 3. In chapter 2, the methodology is discussed, and the eight identified challenges are introduced and described. In chapter 3, these challenges are assessed, and solutions are discussed. In Chapter 4, they are classified into major impediments and minor hinderances based on technology, operational procedures and budget.

2 CHALLENGE IDENIFICATION

This chapter consists of two sections: methodology and challenge description. In the first section, an explanation of the identification and analysis process is given. This is then followed by a brief description of the challenges.

2.1 Methodology

In order to identify the challenges, ETCS level 3 was viewed as a subsystem within the railway system. This enabled us to focus not only on ETCS level 3 but to determine interfaces with the environment. The deployment plans in the Dutch Railways were also taken into account to assess the possible impacts on the railway system. This led to identifying eight unique challenges for the implementation of ETCS level 3:

1. Limited capacity increase
2. Train integrity confirmation
3. Optimization of migration
4. Recovery from degraded modes
5. Executing Maintenance on infrastructure (possessions & machinery)
6. Protection of level crossings
7. Life cycle costs
8. Deployment of ETCS in station areas

These challenges were then studied through literature review and interviews with Dutch railway experts.

2.2 Challenges Description

The challenges identified in section 2.1 are outlined in this section.

2.2.1 Limited Capacity Increase

UIC 406 (Anon., 2004) defines capacity as a relation between the number of trains, average speed, stability and heterogeneity, as shown in Figure 1.

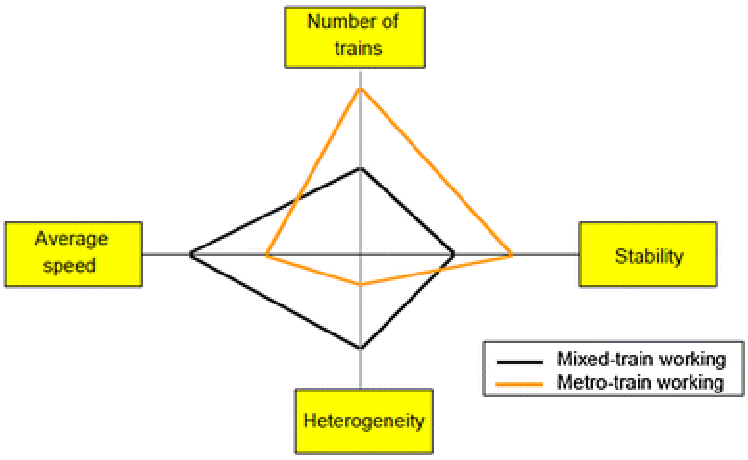

Figure 1 Dependency of UIC capacity parameters for different types of traffic

In the Dutch Railways, with the exception of corridors such as HSL (Hogesnelheidslijn), the main tracks are not dedicated to one type of train, but tracks are shared between various regional and intercity trains (e.g. SLT, SGM, DDZ, VIRM). In addition, there are also tracks which are shared with freight trains. As all these trains have different stopping and running patterns as well as operating speeds, the Dutch Railway is mainly a heterogenous network. The average speed is regarded as neither high nor low as trains are allowed to operate at 140 km/hr on most tracks.

In an open line, the number of trains could be increased by using ETCS level 3 as the headways between them can be reduced. The headways in an open line could be calculated using Equation 1: (Tom Parkinson, 1996)

$$H(l) = \frac{l}{v_l} + \left(\frac{100}{K} + B\right)\frac{v_l}{2d_s} + \frac{a_s t_{os}^2}{2v_l}\left(1 - \frac{v_l}{v_{max}}\right) + t_{os} + t_{jl} + t_{br}$$

Equation 1 Headway Formula for open line

Where,

H(l): line headway, seconds

l: length of the longest train, meters

v_l: line speed, m/s

K: braking service factor, typically 75%

B: separation safety factor, equivalent to the number of blocks

d_s: service deceleration rate, m/s2

a_s: initial service acceleration rate, m/s2

t_{os}: overspeed governor operating time, seconds

v_{max}: maximum train speed, m/s

t_{jl}: time lost to braking jerk limitation, seconds

t_{br}: operator and brake system reaction time, seconds

ETCS improves the time to detect overspeed (t_{os}) as well as the driver's reaction time compared (t_{br}) to ATB EG. However, in an open line, the safety separation factor is the most influencing parameter. Only in ETCS level 3, this factor would change and decrease to the braking distance of the train (with some safety margins), which results in a further increase in the number of the trains.

However, in a network where heterogeneity and average speed are medium to high, increasing the number of trains results in a loss of stability and therefore, capacity would not necessarily increase. In other words, ETCS level 3, on its own, might not increase the capacity of a network and could even result in more congestion in case there is a delay in the operation.

2.2.2 Train Integrity Confirmation

Trains on the Dutch railway network usually are composed of trainsets (passenger trains) or locomotives with several wagons, which are connected by couplers (applicable for both passenger and freight trains). Couplers are prone to failures and when they do, a detached wagon remains on the track. If the splitting of the train is not detected, this scenario could result in a collision. In ETCS level 3, all trackside detection equipment is removed and therefore, the train itself should report its integrity. This requires an additional safety critical functionality.

2.2.3 Optimization of Migration

Migration, in a brown field environment, towards ETCS level 3 could take place in different ways: directly from ATB EG towards ETCS level 3 or from ATB EG via ETCS level 1 or 2 to ETCS level 3. In addition, there could be different strategies for the migration of rolling stock and the trackside equipment: The rolling stock and the trackside could be upgraded step by step in parallel or the upgrade could first start by retrofitting rolling stock and then trackside, as selected for Level 2 rollout in The Netherlands. Moreover, migration in station areas will be another challenge.

Each migration path affects human factors, assets and procedures, therefore, an optimal migration to level 3 which minimizes the consequences should be found. The migration towards ETCS level 3 is more complex than for level 2 due to the implementation of a moving block principle, a new way of train position reporting and the required train integrity check. This will cause changes in the interaction between RBC and interlocking, as well as between on-board and RBC comparing to ETCS level 2. Additionally, from the operational perspective, a different approach will have to be decided for recovery from degraded modes, requiring additional training than in level 2.

2.2.4 Recovery from Degraded Modes

Degraded modes take place when safety systems do not fully operate the way they are supposed to. There could be numerous reasons for degraded modes: An undetectable balise, ETCS failures, etc. These modes and the time required to return to normal operation have a negative influence on KPI's (Key Performance Indicator) related to network availability: Arrival punctuality and train delay. An increase in the number of trains in level 3 increases the impact on the availability KPI's.

Degraded operational modes are more troublesome in ETCS level 3 than in other application levels as well as ATB EG. This is due to the fact that route setting is no longer done based on the trackside train detection equipment status. In level 3 train location, direction, speed and train integrity are monitored on-board and reported to the RBC. Interlocking will obtain the train position status from the RBC. Therefore, the timing issues and availability of the connection between the onboard equipment and the RBC are increasingly important. Consequently, resuming from a degraded mode could take more effort and time, increasing the negative impact on the KPIs.

2.2.5 Executing Maintenance on Infrastructure

Infrastructure requires frequent maintenance in order to keep the rail, ballast, catenary as well as the trackside equipment in good condition, ensure smooth running of the trains and avoid hazardous situations such as derailments. In order to execute maintenance, maintenance trains sometimes drive to the work area on the same track as other trains. Before the work starts, the working area is secured to protect the personnel by taking possessions and reducing the speed of trains on the adjacent tracks as well as setting up warning devices.

The maintenance activity is finished when the possession is lifted, and the track is clear. The removal of trackside detection equipment and lineside signaling in ETCS level 3 raises questions on the planning and arrangement of maintenance train (yellow fleet) movements and taking possessions.

2.2.6 Protection Level Crossings

The operation of level crossings on open lines in the Netherlands is generally autonomous from other signalling equipment. These level crossings are activated in a fail-safe manner by dedicated trackside detection equipment. In case of ETCS level 3, a decision will be needed on how these level crossings should be activated. A possible solution would be to use train data to activate the barriers, but this will require a different operational concept and technical solutions for level crossing installations. Specifically, in case of degraded modes, level crossings will remain a point of attention. Moreover, with increased number of trains, a longer level crossing closing time may become critical and cause more frequent violations by inpatient road users.

2.2.7 Life cycle costs

Life cycle costs include the costs associated to acquisition, operation and maintenance. In general, the lifetime of both on-board and trackside ETCS equipment as well as GSM-R (Global System for Mobile Communications – Railway) are rather short (< 20 years) due to the more use of complex software / hardware units.

The acquisition costs of ETCS should also take into account the costs related to functionality. That is, if more functions are required the costs are higher. In ETCS level 3 there are additional functions needed compared to ETCS level 2 which could result in higher costs, mainly due to more development and testing efforts. These additional functions are:

- Verifying train integrity (on-board ETCS)
- Route controls using train data obtained via RBC (interlocking)
- Exchanging information with interlocking (RBC)

There are no real data of operational costs of ETCS level 3 available at the moment. However, it is expected that the costs of radio communication will increase compared to level 2, mainly due to the amount of transmitted information.

On the other hand, maintenance costs of trackside equipment in ETCS level 3 will be significantly reduced, due to removal of trackside train detection systems. This could potentially make ETCS level 3 more competitive than the other application levels.

More frequent software updates of ETCS level 3, based on software complexity and the early stage of the life cycle (e.g. necessary bug fixing), could however contribute to higher maintenance costs.

For both levels of application (ETCS level 2 and level 3) the announced GSM-R replacement around 2030 will create an extra cost burden.

2.2.8 Deployment of ETCS in station area

In the Dutch ERTMS roll-out plan larger stations are currently excluded. GSM-R limitations and longer awakening times of ETCS on-board compared to ATB EG which would result in reduced capacity are viewed as the main barriers. In ETCS level 3, GSM-R limitations could be even more troublesome due to an increase in data. Therefore, it is important to study the possible consequences of such a chosen strategy for a subsequent implementation of ETCS level 3. Availability, capacity, punctuality, integration and transitions are found to be the main concerns when dedicating the open line to ETCS level 3 and the station to ATB EG:

- The successful transition between ETCS and ATB EG depends on driver's timely confirmation to acknowledge this change in the DMI (Driver Machine Interface).
- Frequent changes from cab signaling to trackside signals near stations require additional attention / action by the driver.

- Connectivity to the RBC, re-issuing of train positions and status reports and MA (Movement Authority) at the transitions could impact the availability.
- Failures, like hardware or communication failures, will require extensive operational scenarios to be considered for degraded modes.
- Integrating information from two different sources (trackside train detection equipment and train data) in one interlocking is complex. This becomes even more complex if two interlockings are considered (one for the stations and one for the open lines) as there would probably be an overlap section.

3 CHALLENGE ASSESSMENT

Throughout the study some challenges were found to be minor as they are expected to be resolved through using current technology, defining manageable operational procedures and allocating financial resources. The others are expected not to be easily resolved at the moment due to technology limitations, complexity in operation or financial risks.

3.1 Limited Capacity Increase

The increase in the number of trains while heterogeneity and average operating speed are medium to high, results in the loss of stability and increased delays in the railway network in ETCS level 3. The measures which could be taken to compensate for the loss of stability are reducing heterogeneity and increasing system reliability. In the Dutch railways, it will be hard to reduce the heterogeneity, as it requires additional infrastructure which is challenging due to physical limits. On the other hand, increasing reliability requires a holistic view to determine bottlenecks, causes and the contribution of failures. A predictive maintenance regime can detect defects before they are experienced. However, this requires changes in the maintenance approach and allocation of financial resources.

Therefore, for a heterogenous network or for a network where heterogeneity cannot be further reduced, achieving a significant increase in capacity by implementing ETCS level 3 is expected to be a major challenge.

3.2 Train integrity Confirmation

The Dutch railway is mostly dedicated to passenger trains and they share limited tracks with freight trains. The passenger trains are either trainsets or trains coupled using BSI and Scharfenberg automatic coupling systems. On several trainsets, passengers are allowed to walk between cars, which implies that the risk of train split is within acceptable limits and these trains can be treated as a "one-piece" equipment. For trains with BSI couplers only a few incidents have been reported. Moreover, the passenger trains consisting of a locomotive and several individual wagons have a continuous electrical connection, which can support train integrity solutions. Therefore, it appears that train integrity for passenger trains in ETCS level 3 is mainly a question of coupler reliability and a minor issue.

In contrast, freight trains are made of a locomotive and several individual wagons which can be very old and joined / detached based on planning logistics. Usually, there is no electrical connectivity between the locomotive and the last wagon of the train. The buffer and chain couplers are usually used to join wagons which are joined by hand and coupling is not automatic. Therefore, the coupling cannot be relied on and it is likely that freight trains would need a Train Integrity Module (TIM) to continuously monitor the train integrity. Different TIM solutions have been proposed for freight trains: brake pipe monitoring devices and end of train / different wagons monitoring. Operators and researchers have addressed a number of concerns for each solution which has made the solutions impractical to use in reality up till now. Freight train TIM solutions concern both technical and operational issues:

1. Life time of the sensors
2. Energy source of the sensors and recycling
3. Mounting (especially when wagons are attached / taken out) and protection of the sensors
4. Communication between sensors and on-board ETCS
5. Maintenance of sensors

6. Reliability of sensors

Consequently, the need to install a train integrity device is a major hinderance due to operational, logistical, mounting and maintenance challenges. Currently, a solution which is feasible, practically and logically manageable does not exist. Confirmation of integrity is therefore expected to be a major barrier for the realization of ETCS level 3 in freight trains.

3.3 Optimizing Migrating

In a brown field environment, an optimum migration path toward ETCS and especially ETCS level 3 should address baseline compatibility, human factors, reliability, route suitability, availability, rolling stock and infrastructure equipment. An analysis on the different migration paths suggests that a one-time upgrade from ATB EG to ETCS level 3 minimizes the consequences and impact on mentioned factors. The consequences are expected to be lower in comparison with migration via level 2 to level 3. The use of dedicated trackside and on-board equipment in the one-time upgrade from ATB EG to ETCS level 3 reduces the complexity of migration.

Therefore, identifying an optimal migration path is not expected to be a major challenge.

3.4 Resuming from Degraded Modes

The absence of lineside signals and trackside detection equipment in ETCS level 3 requires new operational procedures to be defined. These procedures are likely to bring more responsibility towards both the driver and the dispatcher. The increased human intervention to resume from a degraded mode could negatively influence safety and reliability. Additionally, the issue of recovery from degraded modes can impact the implementation of ATO.

Accordingly, dealing with scenarios to resume from a degraded mode is considered to be a major hinderance for the implementation of ETCS level 3.

3.5 Executing Maintenance on Infrastructure

When executing maintenance on the infrastructure in an ETCS level 3 environment two aspects need to be analyzed: possessions and yellow fleet, which are discussed separately.

Track Possessions

In ETCS level 3 possessions can be taken by defining work zones as well as reserving the space between two identifiable objects. In any case, after the track is protected, a TSR can be issued for the trains passing on adjacent tracks to protect the personnel. However, due to the removal of trackside detection equipment, there should be other means to ensure no equipment is left on the track after the maintenance activity is finished.

Since procedures are also used to ensure no equipment are left in case of axle counters, this challenge is expected to be manageable by defining likewise procedures.

Yellow Fleet

In ETCS level 3, route setting requires information from train position, train speed and confirmation of train integrity as trackside equipment are removed. In addition, the movement authority information is also displayed by the on-board ETCS. Therefore, maintenance trains cannot run on tracks dedicated to ETCS level 3 if they are not equipped with the ETCS on-board unit. However, retrofitting maintenance machines could be troublesome due to financial reasons and the lack of available space for installation of the on-board unit. Furthermore, maintenance machines are often deployed internationally, which brings concerns about baseline compatibility. Last but not the least, maintenance machines can also consist of several segments attached to each other. Similar to freight trains, there is no electrical bus, and the coupling might not be reliable. Integrating a TIM with maintenance trains is again troublesome due to the reasons mentioned in 3.2.

Consequently, dealing with maintenance machines in ETCS level 3 is found to be a major barrier.

3.6 Level Crossing Protection

Activation of open line level crossings in ETCS level 3 could be done by separate trackside detection equipment. Although this is not in line with the operational concept of ETCS level 3, it minimizes the risks and guarantees safe operation. Another solution would be to close or replace crossings at grade with bridges / underpasses where possible provided that sufficient investment funds will be available.

As a result, the safe operation of the open line level crossings is a minor concern in ETCS level 3.

3.7 Life cycle costs

The actual life cycle costs of ETCS level 3 cannot easily be predicted due to various uncertainties, including the lack of real data on operational and maintenance costs. This is considered a project risk which should be managed by allocating sufficient budget, so it can be regarded as a minor issue. However, the definition of acceptable risk will be an important decision point for the move toward ETCS level 3

3.8 Deployment of ETCS in station area

Deployment of ETCS level 3 requires a communication technology which could be used not only in an open line but also at stations. GSM-R is a circuit switch technology which supports high reliability for data and voice communication as a channel is dedicated to each user. However, the capacity offered by GSM-R is limited and it is nearing the end of its economic lifetime (2030). The limited capacity is problematic especially for busy stations. Other technologies such as TETRA and GPRS are packet switch and do not offer the same reliability rate for voice communication. LTE-R is perhaps the only circuit switch technology currently available, which will support needs of ETCS level 3, however the operational frequencies, functions and system requirements are yet to be agreed between EU countries. Additionally, the migration strategy from GSM-R to a higher generation of train radio communication will be a challenging process, causing extra costs.

Therefore, the limitations of communication technologies are currently perceived as a major hinderance for the deployment of ETCS level 3.

4 CONCLUSION AND RECOMMENDATION

Despite the potential benefits of ETCS level 3, none of the European countries have decided yet to implement this most advanced application level. In this paper the underlying reasons are identified and analysed. In conclusion, ETCS level 3 faces several major and minor challenges. These major and minor challenges are summarized in Table 1:

Table 1 Challenge Classification

Category	Challenge	Reason
Major	Limited Capacity Increase	ETCS level 3 is not expected to increase capacity significantly. Additional investments are needed to compensate for the loss of stability
	Confirmation of Train Integrity (freight trains and yellow fleet)	No feasible and manageable solution has been identified
	Deployment of ETCS in Station Areas	Limitations of GSM-R and slow progress towards radio communication systems are considered a hindrance for the implementation of level 3 in station areas
	Resuming from Degraded Modes	Safety risks might be introduced due to an increased involvement of operational staff
Minor	Level Crossing Protection	Solutions for this challenge are available by retaining trackside train detection around level crossings
	Optimization of Migration	Direct migration from ATB EG to ETCS level 3 is identified as the optimal scenario. Further study is required to verify this result
	Life Cycle Costs	No major increase in LCC between ETCS level 2 and 3 have been identified, but project risks must be managed.
	Confirmation of Train Integrity for Passenger Trains	Train integrity solutions are easily achievable for most passenger trains
	Dealing with Possessions for Maintenance activities	Operational procedures are expected to be manageable to handle possessions

The severity of the major impediments identified could be less significant in some regional lines. It is recommended to start an ETCS level 3 pilot to help ETCS experts to define and verify optimal operational rules and design principles for a wider implementation. The corridor between Groningen – Roodeschool was selected as a potential pilot line for ETCS level 3 based on technical and operational characteristics of this corridor. There are a limited number of trains (only 2 per hour, per track), the route is dedicated to regional passenger trains (homogeneous system), speed is limited to 80 km/h, there are no level crossings, stations are fairly close to each other. In addition, there is only one train operator (Arriva).

Therefore, major impediments do not apply to this line. GSM-R capacity is most likely sufficient. Increasing the number of trains will not directly decrease stability. Recovery from a degraded mode can be done by simply driving to the next station based on procedures with no or minimum disturbance to the traffic. Maintenance machines would not have to be equipped with on-board ETCS and TIM and could run on the track even by procedures. Furthermore, there is no concern regarding level crossings and train integrity confirmation on the corridor of Groningen - Roodeschool.

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