Rail to Digital automated up to autonomous train operation

D37.3 – Requirements specification to FA1 WP8/9

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EXECUTIVE SUMMARY

Passenger traffic has significantly increased over the last few decades, straining existing technologies and making further capacity increases through traditional methods unfeasible. Current signalling systems have reached their limits. However, new alternatives that align with European objectives – such as creating a high-capacity, integrated railway network by removing interoperability barriers, providing full integration solutions, and speeding up innovation – offer a way forward. ERTMS/ETCS Hybrid Level 3 (HL3), currently known as Hybrid Train Detection (HTD), is one of the implementations that fulfils these purposes. In the context of FP2 R2DATO, WP37 aims at developing migration and deployment strategies to accelerate the implementation of HTD. In this deliverable, we set the requirements specification for the simulations that will be performed by FP1 WP8/9. To this end, we provide a methodology for defining the requirements specification to FP1 WP8/9. In particular, we define performance indicators related to capacity and robustness, where capacity is assessed in simulations without external delays and robustness in simulations with external delays (compared to the undelayed simulations).

This deliverable addresses the basis of the urgent need for railway signalling innovative solutions to enhance railway capacity and efficiency. Many passengers are affected by these constraints, and the consequences of not addressing these issues could severely impact the reliability and sustainability of Europe's transportation network. This report seeks case studies in various European countries to bridge existing gaps and foster consensus on the future direction of railway signalling technology deployment, particularly focusing on ETCS HTD, which offers a balanced solution that combines the benefits of modern train control technologies with the practicality and cost-effectiveness of using existing infrastructure. This makes it an attractive option for rail operators looking to enhance their systems without incurring the high costs and complexities associated with full-scale replacements or upgrades.

Existing literature and prior research highlighted the potential benefits and initial successes of HL3/HTD. However, significant gaps remains, particularly in real-world applicability and performance under varied conditions. Our approach involves a comprehensive analysis of the state-of-the-art of ERTMS/ETCS, followed by the investigation of various case studies and variables pertaining to the HTD design. These variables are the size of the Trackside Train Detection (TTD) blocks, the size of the Virtual Sub Sections (VSS) and the share or types of trains equipped with Train Integrity Monitoring (TIM). The scope encompasses various scenarios across fifteen rail lines and networks in Europe, namely Spain, France, Sweden and the Netherlands. The case studies vary in terms of infrastructure, traffic, general assumptions and scenarios. In particular, the level of complexity can be different depending on the investigated set of performance indicators and scenarios, as well as on the market segment. The investigated market segments include high-speed, mainline, regional, (sub)urban and freight railways. By collaborating with key stakeholders and industry experts, these specifications will be simulated on CAF tool (for the Spanish cases) and RailSys tool (for the Dutch, Swedish and French cases) to model and analyse different performance indicators under various scenarios, including traffic and infrastructure conditions.

The added value of this deliverable is to check based on these requirements specification in which design configurations, scenarios, market segments and cases HTD can be mostly beneficial. This would allow to find the scenarios that would significantly reduce headways, allowing for more trains to operate safely on the same tracks, thus addressing congestion issues effectively. The findings from these test specifications will underscore the EU's added value in standardising and supporting advanced rail technologies, promoting a more integrated and efficient European rail network.

While this deliverable marks a significant basis and milestone for futher developments towards deploying HL3/HTD, further research and innovation are necessary to fully realise the potential of implementing this railway signalling technology. This deliverable is the foundation for additional studies focusing on long-term impacts, cost-benefit or multi-criteria analyses, standardisation, roadmapping and deployment strategies. Future works within FP2 WP37 will include the development of the methodology for optimised placement of (virtual) blocks and determining ETCS HL3 capacity impact analysis based on the FP1 WP8/9 simulations. In addition, next steps will involve evaluating the market acceptance, with a focus on harmonising standards and regulations to facilitate widespread adoption. Continuous advancements in technology and simulation models for various market segments and cases in Europe will be cruciall in refining the system and ensuring its readiness for broader implementation.

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ABBREVIATIONS AND ACRONYMS

ASTP	Advanced Safe Train Positioning
ATO	Automatic Train Operation
CCS	Control Command and Signalling system
DAC	Digital Automatic Coupling
ERTMS	European Rail Traffic Management System
ETCS	European Train Control System
EVC	European Vital Computer
FRMCS	Future Railway Mobile Communication System
GoA	Grade of Automation
GSM-R	Global System for Mobile Communications for Railways
HL3	Hybrid Level 3
HTD	Hybrid Train Detection
ICNG	Intercity Nieuwe Generatie
LZB	Linienzugbeeinflussung (a cab signalling and train protection system used on selected German and Austrian railway lines as well as on the AVE and some commuter rail lines in Spain).
MA	Movement Authority
OTI-I	On-board Train Integrity Function
OTI-L	On-board Train Length Function
PTD	Positive Train Detection
R2DATO	Rail to Digital automated up to autonomous train operation
RBC	Radio Block Centre
SNG	Sprinter Nieuwe Generatie
TCO	Total Cost of Ownership
TIM	Train Integrity Monitor(ing)
TSI	Technical Specification for Interoperability
TTD	Trackside Train Detection
VSS	Virtual Sub-Section

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2   INTRODUCTION

Throughout Europe, passenger traffic has significantly increased over the last few decades, which has led to a limitation of the existing technologies to meet future projected demand. Existing signalling systems have been exploited to such an extent that capacity increase by means of conventional methods is no longer possible. However, new alternatives that fit the overall European objectives (e.g., to deliver a high-capacity integrated European railway network by eliminating barriers to interoperability, providing solutions for full integration, and achieving faster uptake and deployment of innovation) represent a step ahead to tackle the abovementioned limitation: Digitalisation and automation solutions for rail operation (e.g., Automatic Train Operation (ATO) up to Grade of Automation (GoA)4, ETCS Hybrid Train Detection and Moving Block and Advanced Safe Train Positioning (ASTP) among others).

Deliverable D37.3 belongs to FP2 WP37 'ETCS HL3 Deployment Strategies' that aims at developing migration and deployment strategies to accelerate the application of ETCS Hybrid Level 3, currently known as Hybrid Train Detection (HTD), which consequently reap the benefits as quickly as possible and avoids costly investments in new infrastructure as much as possible.

2.1   RELATIONS WITH OTHER FLAGSHIPS, WORK PACKAGES AND DELIVERABLES IN EUROPE'S RAIL

D37.3 relates to FP2 WP15 'Hybrid Level 3 Specification' whose main objective is to align and integrate the HTD approach into the future Functional Railway System Architecture defined by the System Pillar and to apply the defined principles to different kinds of railways. D37.3 also relates to publicly available documents on ETCS HL3 specifications published by the ERTMS Users Group (EUG).

This deliverable is a main input to FP1 WP8 'Development - Simulation and operational feedback for improved planning' and FP1 WP9 'Demonstration - Simulation and operational feedback for improved planning'. FP1 WP8/9 will perform the capacity simulations that align with the requirements specification defined in this deliverable. D37.3 also has dependencies with D37.1 'Standardisation and deployment' since the requirements specification are crucial when defining standardisation and deployment. In addition, it relates to D37.2 'Methodology for optimised placement of (virtual) blocks' since based on the input that will be received from FP1 WP8/9, the method for optimising the design of blocks will be defined. In a further step, the results from D37.2 and from the capacity studies in FP1 WP8/9 will be used as input for D37.4 'Determining ETCS HL3 capacity impact analysis using simulations'.

2.2   OBJECTIVE AND SCOPE

The main objective of this deliverable is to describe the requirements specification for the capacity simulation studies. In particular, this deliverable aims at providing the performance indicators and scenarios to be included in FP1 WP8 and calculated in FP1 WP9 in order to find the right method for applying HTD in several environments and for various market segments. These work packages will perform research on the railway capacity and the number of trains that can be handled, given several infrastructure designs, timetables and technologies installed on the infrastructure side and

train side of the railway system. The description of the scenarios therefore focuses on finding the different methods for infrastructure design from a railway capacity perspective. This deliverable sets the basis for these work packages, that will also perform part of the research on the robustness of the railway system for disturbances. This will be done with only deterministic delays. Stochastic delays are excluded here, because of the lack of good input data (there are no comparable HTD systems in operation). In addition, the reproduction of a scenario in a stochastic environment and the comparison of the results is more difficult (due to the different propagation of knock-on delays based on input delays).

This deliverable focuses on the simulation specifications that will be sent to EU Rail FP1 WP8/9 for calculation and simulation. The analysis of the results of WP8/9 will be performed in Deliverables D37.2 and D37.4 and will there lead to conclusions on block layouts and optimal deployment strategies.

2.3 OUTLINE

The outline of this report is the following: Chapter 3 provides an overview of ERTMS/ETCS with particular focus on ETCS HL3/HTD. Chapter 4 defines the method and performance indicators relevant for the scenarios. It also describes the simulation environments. Chapter 5 provides a description of all scenarios to be simulated in FP1 WP9 for 15 various case studies in the Netherlands, Sweden, Spain and France. Finally, Chapter 6 provides the conclusions for this deliverable.

3 ERTMS/ETCS OVERVIEW

The European Railway Traffic Management System (ERTMS), as introduced in the newly published Technical Specification for Interoperability (CCS TSI 2023/1695), is being implemented all around Europe to ensure interoperability. ERTMS includes the European Train Control System (ETCS) for automatic train protection, the first baseline of ATO up to GoA2, the Global System for Mobile Communications for Railways (GSM-R) and FRCMS. Improving the safety of national and international train traffic, bringing benefit in terms of Total Cost of Ownership (TCO) of the entire Control Command and Signalling system (CCS), by reducing trackside assets, and increasing capacity are among the most relevant advantages of ERTMS.

Depending on the application level, ETCS trackside and on-board subsystems are characterized by specific equipment on both the track and the train, their interaction, and their functions. The ETCS levels establish different uses of ERTMS as a train control system [1]:

- ETCS Level 1: track-to-train spot communications, where a significant and costly amount of trackside elements are required to control the movement of the train. Train detection and train separation are performed by the trackside equipment of the underlying signalling system.

- ETCS Level 2: continuous communications between the train and the track, which enable a reduction in OPEX and CAPEX and increase line capacity. Train detection and train separation can be performed by the Radio Block Centre (in cooperation with the train which sends position reports and train integrity information) and/or by other trackside equipment.

ETCS Level 2 is therefore a crucial player in the search for delivering better capacity, reducing costs, improving flexibility, and increasing reliability of the railway network since dependency on trackside equipment is minimized.

ETCS Hybrid Level 3 (HL3), currently known as Hybrid Train Detection (HTD) based on the ERTMS Users Group [2], is one of the ETCS L2 implementations that fulfils these purposes. In the context of R2DATO, WP37 aims at developing migration and deployment strategies to accelerate the implementation of HTD.

HTD is a concept that uses pre-configured fixed virtual blocks for the separation of trains. The virtual blocks can be used by trains that are able to send integrity confirmation in the position report, while trackside train detection is still used for the separation of trains which are not able to send integrity confirmation. The trackside train detection is also used for the handling of degraded situations. The main advantage of HTD is the reduction of trackside implementation cost (extending current Trackside Train Detection (TTD) blocks), an improved capacity performance (by introducing shorter blocks), or a combination of both.

3.1 ETCS HYBRID LEVEL 3/HYBRID TRAIN DETECTION OBJECTIVE

The ERTMS Users Group [2] discuss how ETCS HL3/HTD aims at increasing line capacity and optimizing the use of existing infrastructure. HTD improves train detection and safety by combining track-side and on-board systems. In addition, HTD facilitates a smooth transition from conventional systems and ensures compatibility. Therefore, the main goal of HTD is to improve railway system capacity, safety, and efficiency while reducing costs and enhancing operational flexibility.

3.2 ETCS HYBRID LEVEL 3 SYSTEM ARCHITECTURE AND FUNCTIONALITY

The reference architecture for HTD is the current ERTMS architecture defined in the TSI (omitting some ETCS level 1 features), as shown in Figure 1 [3].
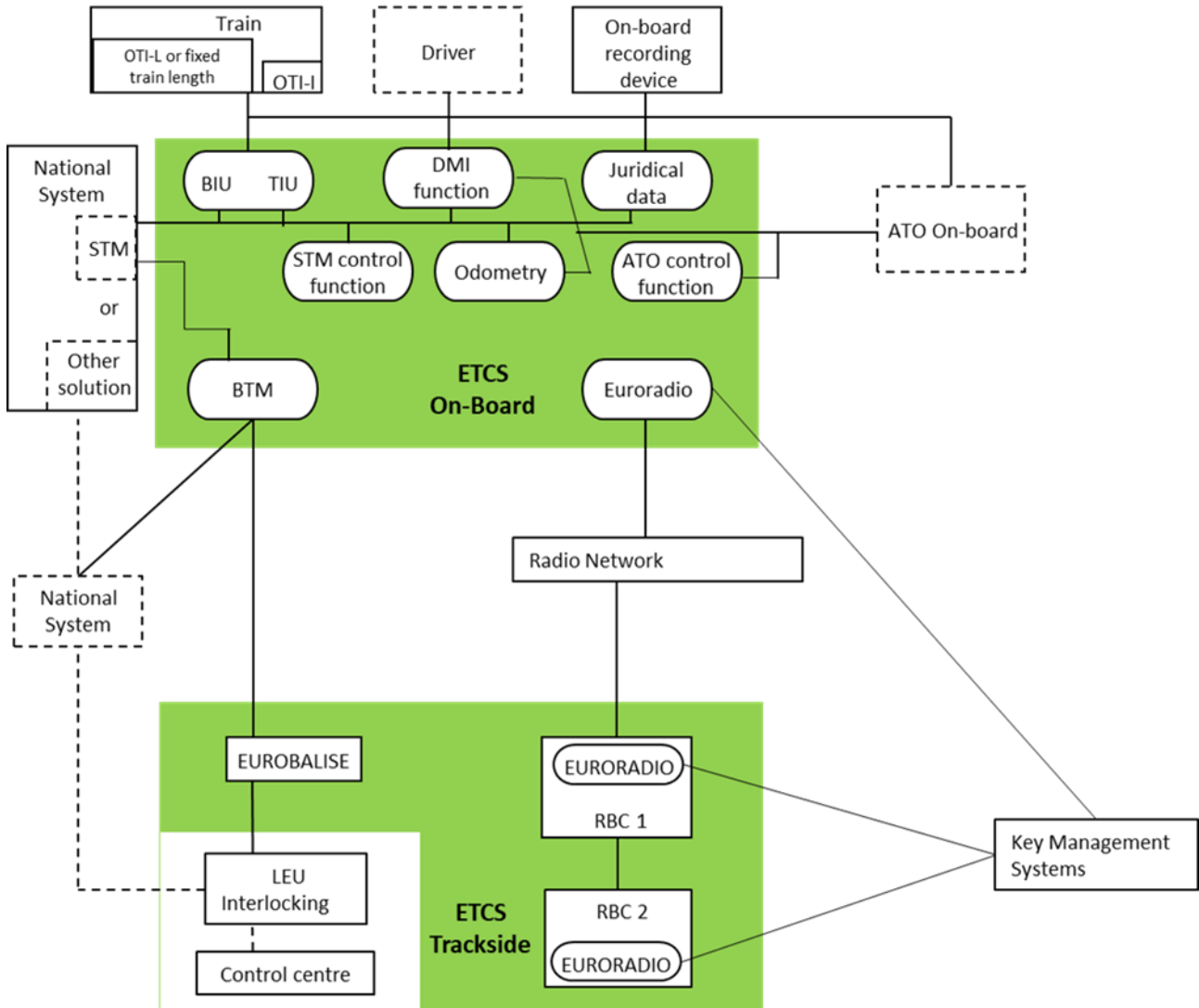
Figure 1: Current ERTMS architecture defined in the TSI [3]

Regarding this architecture and the associated functionality of HTD, the following considerations are made:

In general, the trains without ETCS but with the National System can be managed in HTD as "ghost trains" (detected by the TTD but not reporting its location to the trackside). These features are subject to specific application analyses, as the behaviour of the National System is not harmonised.

The HTD-ready trains are generally expected to be equipped at least with a system providing the train integrity information to the EVC (OTI-I) and optionally a system providing the safe train length (OTI-L). Integrated devices providing more than one information are possible. Trains equipped with ETCS but without OTI-I can be allowed in HTD, but treated as non-integer trains, still having the

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HTD performance however giving to the following train a performance analogue to ERTMS Level 2 with only TTD.

The functionality of the system relies in the Hybrid Train Detection Concept. This concept is based on the following essential components/functionalities:

- Positive Train Detection (PTD): PTD relies on information received from the train itself. It uses position reports sent by the train, including data such as position, integrity status, and safe train length. When a train reports "integrity confirmed," it becomes an "integer train". The trackside can use this information to determine the train's location and manage train movements. PTD allows for reduced trackside infrastructure since it does not rely solely on physical sensors (such as track circuits or axle counters).
- Trackside Train Detection (TTD): TTD is the conventional method of train detection using physical sensors installed along the track (e.g., track circuits or axle counters). In the HTD system, the TTD sections are subdivided into smaller units called Virtual Sub-Sections (VSSs). Each VSS corresponds to a portion of the TTD section and has its own occupation status (free, occupied, ambiguous or unknown). TTD information can confirm whether a train is or not physically present on a VSS.
- Virtual Sub-Sections (VSS): VSSs are the building blocks of the HTD system. They allow for finer granularity in train separation. Each VSS can be in one of four states (based on trackside information):
  o Free: No train is located on the VSS.
  o Occupied: An integer train is present on the VSS, and no other vehicle is behind it.
  o Ambiguous: A train is present, but there might be another non-connected vehicle behind it.
  o Unknown: No train is confirmed on the VSS, but its status is uncertain.

  VSS states are dynamically updated by means of a VSS state machine, which is operated based mainly on position reports, TTD information, the status of the HTD timers and Movement Authority (MA) information.
- Train Location: The concept of "train location" defines the trackside view of the portion of track currently occupied by a connected train. The front end of the train location is determined by the train's max safe front end position and train detection information. According to the EUG document on the HTD Principles (published on 16 July 2024), the front end of the train location is not depending on the integrity status. The train integrity is based on the rear end of the train location which is "established" for a train treated as integer or "assumed" for a train which is not treated as an integer [2]. Therefore, the rear end of the train location is either "established rear end" (for integer trains) or "assumed rear end" (for non-integer trains).
- HTD timers: For handling degraded situations, there are two types of timers defined within the HTD concept:
  o Waiting timers: they are aimed to avoid unnecessary changes in the state of a VSS due to the asynchronicity of train position, train integrity and TTD information. They are:
    ▪ Mute timer: used at the trackside for each connected train to consider after a defined time that the communication with that train is lost;
    ▪ Wait integrity timer: used at the trackside for each connected train to consider after a defined time that the integrity of that train is lost when no integrity information is available;

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- Shadow train timer: used to prevent wrongful detection of shadow trains (ghost trains chasing normal HTD operated trains).
  - o Propagation timers: they are implemented in the trackside to avoid unnecessary propagation of the state "unknown" to VSS sections for which there is no immediate risk that a rail vehicle could be located on them. They are:
    - disconnect propagation timer: used at the trackside for each track section to consider after a defined time that an "unknown" track section should be propagated after train disconnection;
    - ghost train propagation timer: used to prevent the risk of undetected ghost trains;
    - integrity loss propagation timer: used at the trackside for each track section to consider after a defined time that an "unknown" track section should be propagated after integrity loss.

The introduction of VSS in general does not change the principles of route setting and handling of MAs since VSSs are treated in the same way as sections with TTD. HTD is an enhanced train detection concept too allow an optiomal use of PTD and TTD train detection systems. HTD can be used in train centric or geographical safety sytems and with conventional signalling systems. The HTD can be used with the existing legacy rules and interfaces. To give an example, it is possible that the RBC today takes as a necessary but not sufficient condition to send an MA in Full Supervision that status "free" of a TTD. With the implementation of HTD, the same RBC is expected to use instead as input condition the status "free" of one or more VSSs belonging to the same TTD.

4 METHODOLOGY

This chapter presents the methodology used for defining the requirements specification to FP1 WP8/9. In particular, in section 4.1 we present the performance indicators for the capacity simulation studies. In 4.2 we define the set-up of scenarios and variables, followed by the description of the simulation environments CAF tool and RailSys in 4.3.

4.1 PERFORMANCE INDICATORS

There are several performance indicators to be assessed after executing the simulations. Together, these performance indicators will provide a complete overview of the effects of ERTMS HL3/HTD regarding capacity. These relate to the general terms of capacity and robustness. The capacity will be assessed in simulations without external delays and the robustness in simulations with external delays (compared to the undelayed simulation). Both require different performance indicators that are elaborated in Table 1 and Table 2.

The definitions of the performance indicators for scenarios without external delays are explained in Table 1.

Table 1: Capacity-related performance indicators for scenarios without external delays

Performance indicator	Unit	Explanation	Utilisation
Headway	Minutes and seconds	Minimal time between 2 trains with which the second can follow the first on the whole trajectory just without hindrance.	In simulations that only consider 2 trains at the same time (Spanish, French and Swedish case studies).
Relative capacity utilisation	% (capacity utilistation / 60 min)	Timetable compression method according to UIC-406 leaflet, to be performed on one corridor at a time without merging traffic. Trains run the whole trajectory strictly unhindered.	In simulations that consider a complete timetable (French, Swedish and Dutch case studies).

The scenarios of the Swedish southern mainline and the Dutch SAAL corridor will be assessed further for the aspect of robustness by letting a train block the other traffic for a set number of minutes. This gives the insight in how quickly the block layout given a particular traffic pattern helps to solve the congestion. The definitions of the performance indicators for scenarios with external delays are explained in Table 2.

Table 2: Robustness-related performance indicators for scenarios with an external delay

Performance indicator	Unit	Explanation
Recovery time	(Hours), minutes and seconds	Time after which there are no trains running behind their schedule as in the unhindered simulation.
Number of affected trains	Trains	Number of trains that have a changed running time due to the hindrance and congestion compared to the unhindered simulation.
Total delay	(Hours), minutes and seconds	The additional running times compared to the unhindered simulation, summed up over the affected trains.

4.2 SET-UP OF SCENARIOS AND VARIABLES

This section describes how the scenarios have been set-up to achieve the aim of this deliverable. Note that there are several benefits of HTD that will not be the focus of this deliverable. Only research related to capacity and robustness will be the focus of these case studies as stated in Section 4.1. For capacity, the headway between two following trains will be computed or the relative capacity utilisation of a full timetable will be calculated. For robustness calculations, some scenarios will be set up in which a train blocks the corridor for a set time period, where the aim is to study the recovery time, number of affected trains and total delay.

Simulation with stochastic disruptions will not be included in this stage, for several reasons. The input data of real disruptions is not available for future or hypothetical situations analysis, scenarios are harder to reproduce or compare and finally this method requires many runs which makes simulation and analysis more time consuming. Overcoming these issues does not outweigh the benefits, so stochastic analysis is not foreseen in this deliverable. Therefore, all simulations will be deterministic with no delays or fixed delays in the simulation.

In every scenario, we define a reference situation, using the current or future base information about the track and calculating the headway or relative capacity utilisation. After that, and through variations of the physical blocks and incorporating virtual blocks, according to what is proposed in each scenario, improvement in capacity will be sought in these cases where the capacity is the main objective. When the objective is cost reduction and only keeping equal capacity, we look for keeping the current headway but changing the physical blocks into VSSs.

These results are used not only in this work package in tasks T37.3 and T37.5, but also in FP2 WP32.

Each case study described in Chapter 5 includes four parts:

- Infrastructure: a description of the part of the railway network used in the case studies, either the current infrastructure for existing lines or the planned infrastructure for a greenfield situation.

- Traffic: a description of the train services on the delimited network and possible alterations that could influence the scenario. The described traffic could be either current traffic (high flows

where HTD could help increase robustness), or future traffic flows demands that could only possibly be achieved with HTD.

- Assumptions: this section describes additional assumptions for the simulations, like timetable principles.

- Scenarios: a description of the different infrastructure and traffic scenarios. They always relate to reference scenario and then build up in order to make the results comparable with only one variable changed at a time. The variables are described below.

For our simulation studies of HTD there are three variables of interest: the lengths of the TTD blocks, the lengths of the VSSs and the availability of TIMs on trains. These variables are defined for each scenario and depend on the state and aim of each network.

- Size of the TTD blocks [m]: A benefit with HTD is the possibility to extend the current TTDs without affecting capacity negatively. This means that for some scenarios varying the size of TTD is of interest.

- Size of the VSS [m]: For creating additional capacity with additional blocks it is not necessary anymore to add axle counters or loops, but it can be done with adding VSSs. Therefore the size of VSSs is crucial for the capacity computation.

- Share of trains equipped with TIM [% or based on train type]: The availability of TIM equipped trains in the traffic pattern has impact on the capacity and robustness. This might be a percentage of the trains or defined as one train category to have a TIM and another to not have a TIM.

4.3 SIMULATION ENVIRONMENTS

Two simulation environments will be used in EU Rail FP1 WP9 for assessing the case studies of this work package: the tool of CAF for exploratory research based on the headway of two trains for the Spanish case studies and RailSys for the French, Swedish and Dutch case studies that involve a complete timetable and in some cases external delays. Both simulation environments are briefly described in Sections 4.3.1 and 4.3.2.

4.3.1 CAF tool

The simulations for the Spanish cases will be performed in the CAF tool. It is focussed on calculating headways. Therefore the tool needs information about the rolling stock and about the technical and the physical characteristics of the track. The tool is limited to work with two trains at the same time: the predecessor and its follower. According to this information, it offers the headway between them as a solution.

4.3.2 RailSys

The simulation software RailSys is an integrated microscopic planning tool, developed by RMCon. RailSys is widely used in the railway sector by infrastructure managers, railway undertakings consulting firms and research institutes [4]. RailSys features native ERTMS/ETCS support and

detailed calculations of the ETCS braking curves. Infrastructure and rolling stock are modelled on a microscopic level, which provides sufficiently detailed settings for the modelling of HTD and analytical possibilities for the results.

Infrastructure models are needed for all scenarios which utilise RailSys. In case of current lines, existing models will be used as a basis of the studies. For some scenarios, ERTMS/ETCS will need to be implemented in the models. HTD needs to be designed and applied to all existing models for the relevant scenarios. It is important that relevant settings are correctly used to achieve a credible simulation result. Coordination between partners is necessary for this purpose.

For the evaluation of capacity utilisation, the UIC-406 compression method in RailSys will be used. In RailSys, the interpretation of UIC-406 is based on the compression of sequential timetable train paths within divided sections [4]. According to the method, RailSys identifies conflicts in the timetable and moves affected trains exactly unhindered behind the conflicting train. The outcome from the RailSys computation is the capacity utilisation which will be generated from specific case studies as described in Chapter 5.

5 CASE STUDIES AND SCENARIOS

To fulfill the aims of developing migration and deployment strategies to accelerate the application of ETCS HTD, the several research scenarios have been defined according to the set-up described in the previous chapter. These scenarios are used for evaluating the requirements specification of HTD. The lines have been chosen where the main advantages of HTD can be found, both in terms of reduction of trackside implementation costs and improvement of capacity performance.

The general outline is that the Spanish cases and a Swedish case will be described and analysed based on headways. Thereafter, the French and Swedish cases will be assessed on capacity by relative capacity utilisation. Finally another Swedish case and the Dutch case are desribed and analysed for relative capacity utilisation and robustness aspects.

Since there are many case studies described in this chapter, Table 3 provides an overview of the locations, market segments, network length, reference signalling system and performance indicators. The explanation follows in the paragraphs of every separate case study.

Table 3: Overview of key elements of case studies and scenarios

Nr	Country	Location	Market segment	Network length [km]	Reference signalling system	Performance indicators		
						Headway	Relative capacity utilisation	3 PI' s for external delays
5.1	Spain	Atocha commuter tunnels	Urban	7	L1	X		
5.2	Spain	Madrid C-5 cercanías	Sub-urban	45	Class B	X		
5.3	Spain	Madrid - Torrejón de Velasco	High-speed	36	L2	X		
5.4	Spain	Barcelona - Figueras	Mainline	130	L2	X		
5.5	Spain	León - Guardo	Regional	26	Class B	X		
5.6	Spain	Lérida - Reus	Freight	64	L2	X		
5.7	Spain	Cercanías Barcelona	Mainline	8	L2	X		
5.8	France	Lille	Sub-urban	30	L2	X	X	
5.9	France	Bretagne pays de Loire (LNOBPL)	Mainline	250	L2	X	X	
5.10	Sweden	Stockholm Citybanan	Urban	6	L2		X	

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Nr	Country	Location	Market segment	Network length [km]	Reference signalling system	Performance indicators		
						Headway	Relative capacity utilisation	3 PI' s for external delays
5.11	Sweden	East link	Mainline / High-speed	160	L2	X		
5.12	Sweden	Southern mainline (Norrköping – Mjölby)	Mainline	79	L2		X	X
5.13	Netherlands	SAAL-corridor: Schiphol – Amsterdam – Almere – Lelystad	Mainline / (Sub)urban	120	L2		X	X

5.1 SPAIN: ATOCHA COMMUTER TUNNELS

5.1.1 Infrastructure

This is a double-track ETCS Level 1 section for commuter trains between Chamartín and Atocha stations, with a length of 7.4 km, this section is selected for study as it is a central node where many lines come together, more specifically, almost all of Madrid's commuter lines.

There are two options for this route: through Recoletos tunnel stopping at Recoletos station (Chamartín-Nuevos Ministerios-Recoletos-Atocha) or through Sol tunnel stopping at Sol station (Chamartín-Nuevos Ministerios-Sol-Atocha). Figure 2 displays the schematic of the lines involved.

Figure 2: Schematic section line of the Commuter tunnels [5]

At Nuevos Ministerios station, there are sidings on each track so that different speed trains can overtake each other if necessary.

The technical drawing of the track layout is shown in Figure 3.
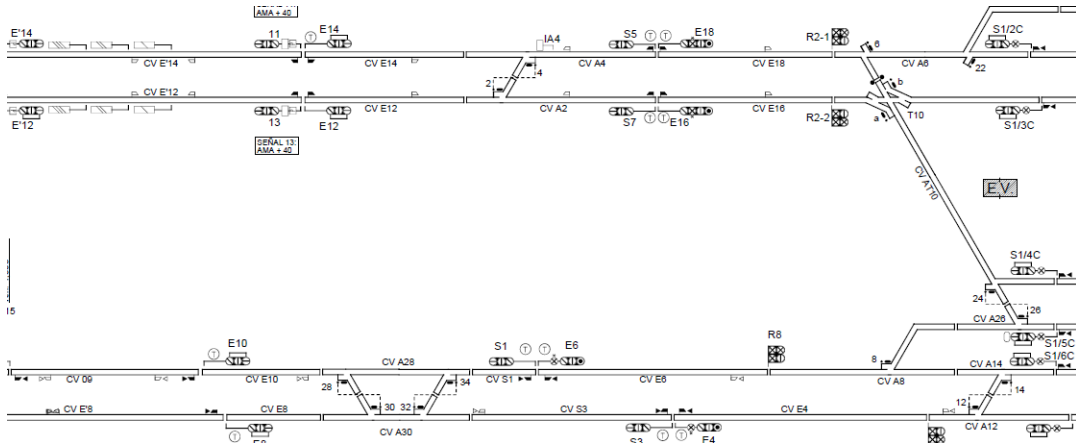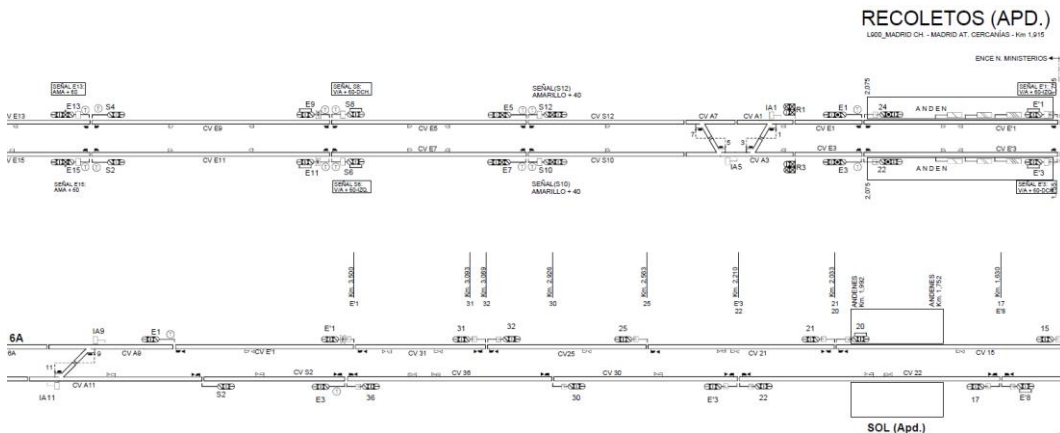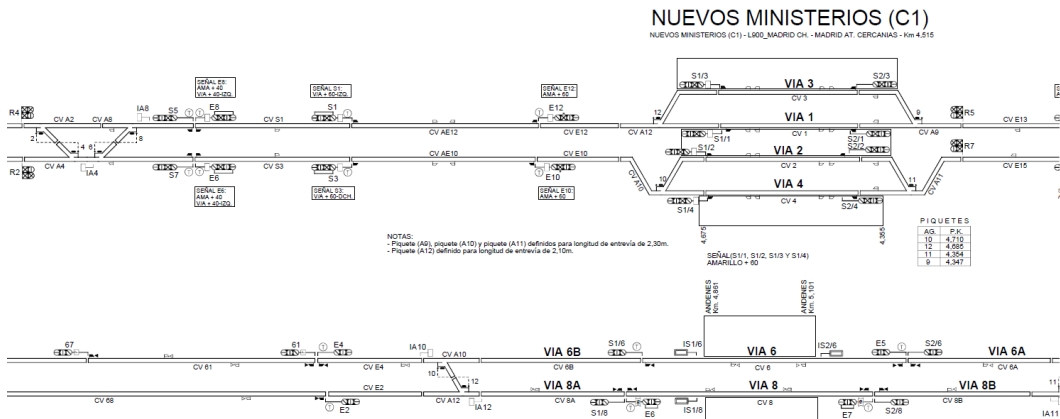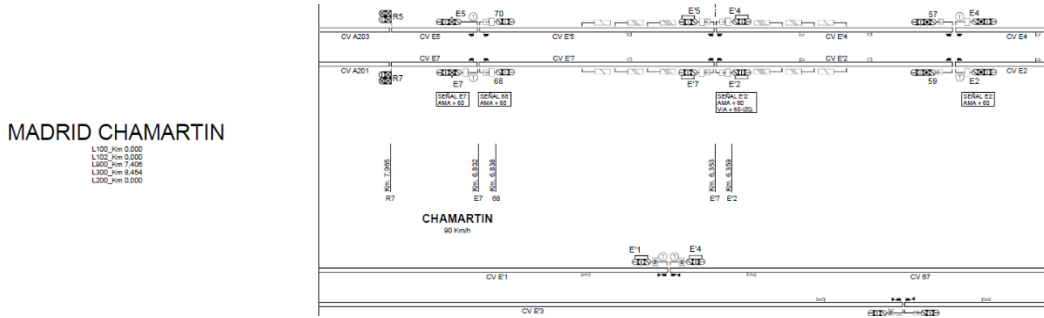
Figure 3: Commuter line Madrid Chamartin - Madrid Atocha [6]

5.1.2 Traffic

The traffic of the line consists of commuter trains every 7 minutes on both Recoletos and Sol routes, regional trains every 45 minutes through Recoletos and every 3 hours through Sol. The timetable for the Atocha commuter lines can be found in [6]. The maximum speed of the trains is 90 km/h.

5.1.3 General assumptions

All the trains are equipped with TIMs in the reference scenario.

TIMs conditions are changed for the rest of the simulations as explained in the following section.

5.1.4 Scenarios

For the scenarios to be simulated in this section, two objectives are pursued. On the one hand, the aim is to achieve an increase in capacity; on the other hand, the aim is to reduce costs. Considering the following described conditions, the goal is to find a balance between both, cost and capacity.

In order to achieve these objectives, different scenarios are proposed to check, by simulation, if, firstly, the defined goals are achieved and, secondly, if the results are valid.

First, the reference scenario is defined, which is the current track and traffic status, and will be used to compare the rest of the scenarios to be simulated. In this way, we will obtain an answer on whether we have improved the defined goals regarding the current state.

These scenarios are determined by modifying different elements: making changes in the infrastructure (TTD), modifying the integrity of the rolling stock and incorporating VSSs.

Since the objectives to be achieved for this line are both capacity improvement and cost reduction, the chosen scenarios are the following:

In relation to traffic and rolling stock, two alternative conditions are defined: the first is that it is assumed that commuter trains are equipped with TIMs, whereas regional trains are not equipped with it (Scenarios 1 and 2 in Table 4). The second condition is to consider that all the trains are equipped with TIMs (Scenarios 3 and 4 Table 4). This way, differences regarding capacity between those cases can be compared, where it could be visualized whether a decrease in capacity is obtained as a result when not having TIMs equipped.

Regarding TTDs, in the first scenario, the current TTD layout remains with no change. As mentioned, the cost reduction goal is also pursued, therefore, a case where TTDs are reduced between stations to the minimum is defined. By reducing the number of physical TTDs, a cost reduction could be obtained as a result of not installing them when designing a track.

However, if we only reduce the TTDs, this could be reflected in a decrease in capacity, hence, VSSs are incorporated. For the length of these, a methodology for optimal VSS lengths for each specific line should be followed.

However, in the absence of such methodology, it is intended to make an engineering study of the line, where the most critical sections of the track will be identified and analyzed. Firstly, a maximum VSS length (taking into account the TTD maximum size) is implemented, then, a simulation is runned and a new VSS size decreased by multiples of 25 is simulated. Several iterations are performed

through simulations until a size is reached (minimum VSS length of 25 meters [2]) from where the results improve in a non-significant way concerning the objective of the defined scenario, cost reduction and capacity increase for this case, so the optimal length is established. The proposed scenarios for the Spanish Atocha Commuter Tunnels are shown in Table 4.

Table 4: Proposed scenarios for Spanish Atocha Commuter Tunnels case

Scenario	TTD	VSS	Rolling Stock
Reference	Current (ETCS Level 1)	-	Current
1	Current	From 25 m to max. TTD length	Passenger trains with and without TIMs
2	Reduction of TTD between stations	From 25 m to max. TTD length	Passenger trains with and without TIMs
3	Current	From 25 m to max. TTD length	All trains with TIMs
4	Reduction of TTD between stations	From 25 m to max. TTD length	All trains with TIMs

5.2 SPAIN: MADRID C-5 CERCANÍAS

5.2.1 Infrastructure

This is a double-track commuter line between Mostoles-El Soto and Humanes with 21 stations in between them, with a length of 45.1 km. The used signalling system is Class B.

This line is selected for study as it is the only one in Spain working with automatic driving, where it is expected to eliminate this LZB and install ERTMS.

Figure 4 represents the scheme of the line where all the 21 stations appear. A fully technical description of this line is available at [7].

Figure 4: Schematic C5-line: stations, halts and connections [5]

5.2.2 Traffic

Unlike the rest of the commuter network, the C-5 line has similar frequencies to the Madrid Metro lines.

The traffic consists of commuter trains every 5 minutes during peak hours and every 10 minutes during off-peak hours.

This is the only case study where there is a differentiation between peak and off-peak hours regarding train frequency.

The maximum speed of the trains is 155 km/h.

5.2.3 General assumptions

Stations are closer to each other than the rest of the Madrid commuter lines and it has a particular signalling and supervision system, the LZB, a train protection system with continuous transmission of information and monitoring of the vehicle speed.

All the trains are equipped with TIMs in the reference scenario.

TIMs conditions are changed for other experiments as explained in Section 5.2.4.

5.2.4 Scenarios

The objectives of this scenario are also cost reduction and capacity increase, where different infrastructure, rolling stock and VSS conditions are defined.

Regarding rolling stock, it is defined a case where all the trains are equipped with TIMs and another case where trains are not equipped with TIMs. This way, we could compare the two situations in terms of capacity.

Concerning trackside conditions and in order to get a cost reduction, a condition where TTDs are reduced between stations with no change in stations is defined while another condition is defined where the current TTD layout is maintained.

In the case of VSSs, once the knowledge acquired in the Atocha commuter tunnels study for determining the most critical sections can be applied while using the previously mentioned methodology for determining the optimal VSS size for each case, several simulating iterations starting from the minimum possible VSS length will be carried out. The proposed scenarios for the Spanish Cercanías C-5 case are displayed in Table 5.

Table 5: Proposed scenarios for Spanish Cercanías C-5 case

Scenario	TTD	VSS	Rolling Stock
Reference	Current (LZB)	-	Current
1	Current	From 25 m to max. TTD length	All trains without TIMs
2	Reduction of TTD between stations	From 25 m to max. TTD length	All trains without TIMs
3	Current	From 25 m to max. TTD length	All trains with TIMs
4	Reduction of TTD between stations	From 25 m to max. TTD length	All trains with TIMs

5.3 SPAIN: MADRID - TORREJÓN DE VELASCO

5.3.1 Infrastructure

This is an ETCS L2 double-track high-speed line between Madrid and Torrejón de Velasco with a length of 35.85 km, this line goes through 8 different Madrid city stations: Madrid Chamartín, Concha Espina, Serrano, Madrid-Jardín Botánico, Entrevías, Abroñigal, Canal del Manzanares, Cerro de los Ángeles, Parla Norte, and Torrejón de Velasco.

Figure 5 provides the technical drawing of the line where all these stations can be found.

Interne
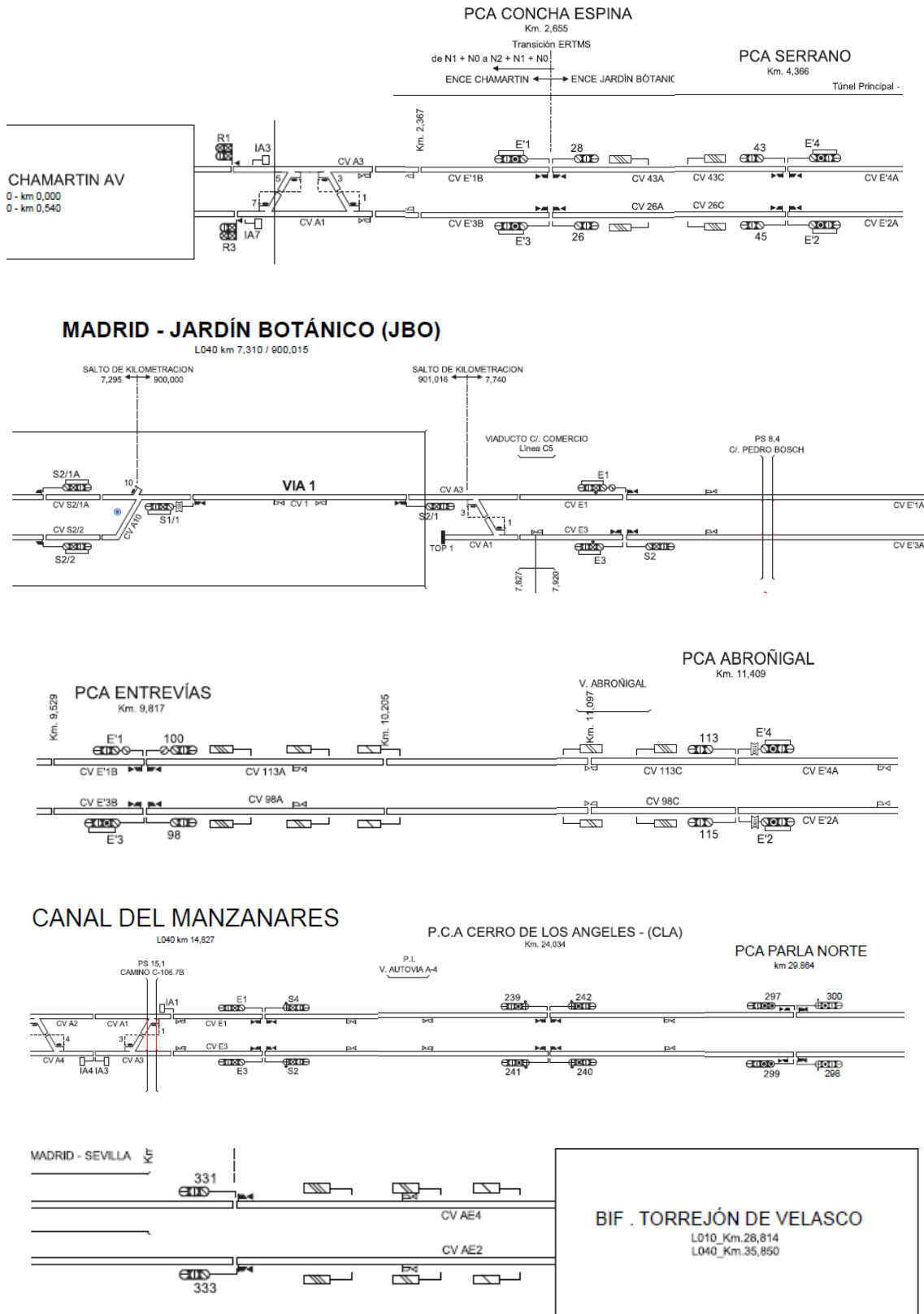
Figure 5: High-speed section Madrid-Torrejón de Velasco [5]

5.3.2 Traffic

This line consists of high-speed trains from Chamartín towards Levante (southeastern part of Spain) every 20 minutes.

The maximum speed of the trains is 240 km/h.

5.3.3 General assumptions

All the trains are equipped with TIMs.

5.3.4 Scenarios

The objective set for this line is to improve capacity as well as reducing costs, for which rolling stock, TTD and VSS conditions are defined.

A case where the TTDs are reduced between stations for reducing costs is defined and another where the TTDs remain as they are now in the reference scenario. However, VSSs are incorporated in order to get a possible increase in capacity. The plan for the VSS length is the same as in the scenarios of the other case studies (see for instance Section 5.1.4), to develop a methodology for reaching the optimal size, from the capacity increase point of view. The proposed scenarios for Madrid-Torrejón de Velasco are shown in Table 6.

Table 6: Proposed scenarios for Spanish Madrid-Torrejón de Velasco case

Scenario	TTD	VSS	Rolling Stock
Reference	Current (ETCS Level 2)	-	Current
1	Current	From 25 m to max. TTD length	All trains with TIMs
2	Reduction of TTD between stations	From 25 m to max. TTD length	All trains with TIMs

Interne

5.4 SPAIN: BARCELONA - FIGUERAS

5.4.1 Infrastructure

This is a double-track high-speed line between Barcelona and Figueras with a length of 130 km. It is equipped with ETCS L2. A full description of this line is available at [8]. The stations are the following: Barcelonna-Sants, Sant Andreu Comtal, Mollet, Llinars, Riells, Vilobi d´Onyar, Girona, Figueres.

5.4.2 Traffic

The traffic of the line consists of mixed traffic: freight trains every 1.5 hours, regional trains (200-250 km/h) every 2 hours and high-speed trains (250-350 km/h) every 3 hours.

5.4.3 General assumptions

Current trains are equipped with TIMs. For the simulations, passenger trains remain equipped with it and freight trains will not.

5.4.4 Scenarios

The objective to reach by this simulating experiment is to get an increase in capacity. This is a mainline with high-speed and freight traffic between Madrid and Torrejón de Velasco.

Concerning rolling stock, passenger trains will remain all equipped with TIMs as it is more critical because of punctuality and other possible service problems. Freight trains will not be equipped with TIMs because it is deemed less critical than for passenger trains, primarily due to punctuality concerns and their associated impacts.

The TTDs remain as they are now in the reference scenario. However, VSSs are incorporated in order to get an increase in capacity. The VSS lengths will be the ones taken from the methodology for reaching optimal sizes through iterations by simulating this specific scenario taking into account the critical sections and the increase in capacity objective. The proposed scenarios for the Spanish case Barcelona-Figueras are displayed in Table 7.

Table 7: Proposed scenarios for Spanish Barcelona-Figueras case

Scenario	TTD	VSS	Rolling Stock
Reference	Current (ETCS Level 2)	-	Current
1	Current	From 25 m to max. TTD length	Passenger trains with TIMs and freight trains without TIMs

5.5 SPAIN: LEÓN - GUARDO

5.5.1 Infrastructure

This is a single Class B regional line from Asunción Universidad to with a length of 93,82 km. In this case, a 26 km section from Asunción Universidad to Matallana will be studied, the stations are the following: Asunción Universidad, San Feliz, La Robla and Matallana. There are sidings in some stations in between them where trains can overtake and come across each other.

It is expected to have demonstrators for ATO, ASTP, FRMCS in this line for the next Europe´s Rail call.

Figure 6 shows the technical drawing of the track layout where all the stations through where this line goes.

Interne
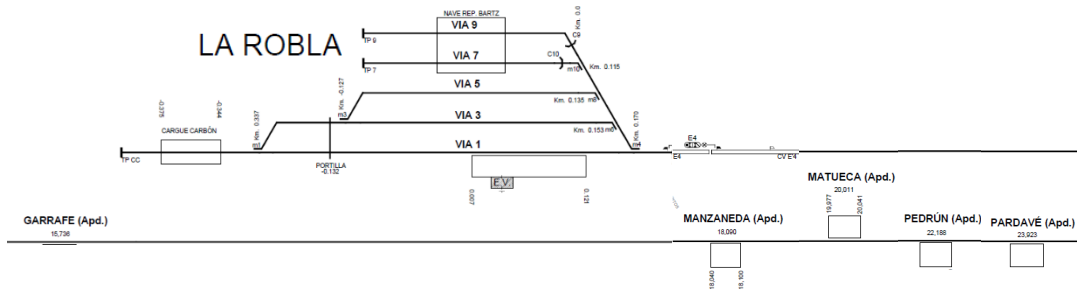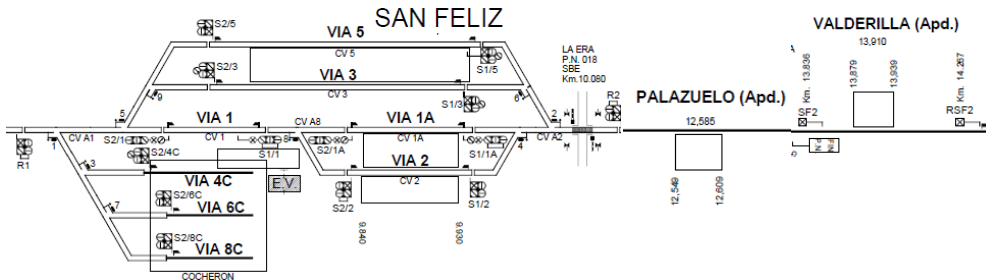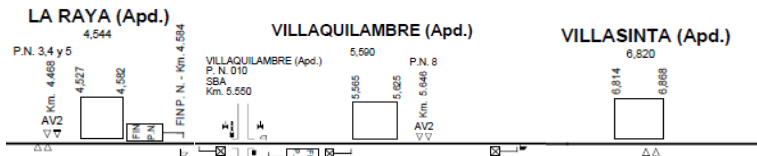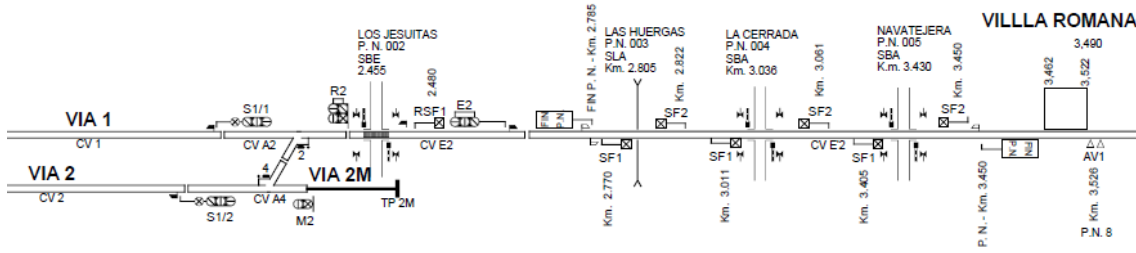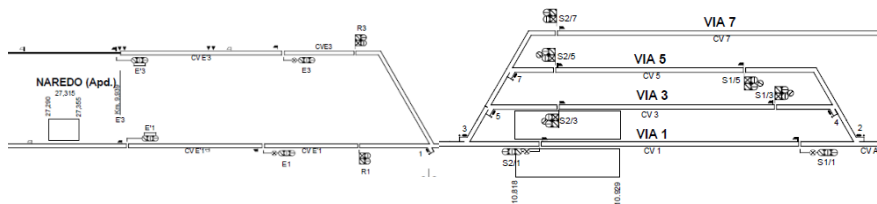
Figure 6: Schematic single-line section Asunción Universidad-Matallana [9]

5.5.2 Traffic

The traffic of the line consists of regional trains every 1.5 hours from Asunción Universidad,12 commuter trains per day and 2 long distance trains per day towards Bilbao (out of the study).

The maximum speed of the trains is 70 km/h.

5.5.3 General assumptions

Passenger trains are all equipped with TIMs whereas freight trains are not.

5.5.4 Scenarios

The main objective for this line is to reduce costs, hence, conditions for rolling stock, TTD and VSS are determined.

Regarding TTDs, there is a situation in which one TTD remains between stations and one TTD in stations is defined.

The strategy for the VSS length is the same as in the scenarios of the previous case studies, to use the developed methodology for reaching the optimal size from the cost reduction point of view once an engineering study for this concrete line has been done. The proposed scenarios for León-Guardo are shown in Table 8.

Table 8: Proposed scenarios for Spanish León-Guardo case

Scenario	TTD	VSS	Rolling Stock
Reference	Current (Class B)	-	Current
1	Minimum (1 TTD between stations, 1 TTD in stations)	From 25 m to max. TTD length	Passenger trains with TIMs

5.6 SPAIN: LÉRIDA-REUS

5.6.1 Infrastructure

This is a single regional line with ETCS L2 from Lérida to Reus covering a length of 64 km. The study covers the following stations: Lleida Pirineus, Puigverd de Lleida, Juneda, Les Borges Blanques, Canal d´Urgell, Vinaixa, Riu Milans, L´Espluga de Francoli, Montblanc, Vilaverd, La Plana-Picamoixons, Base de Alcover, Alcover and Reus.

5.6.2 Traffic

The traffic consists of mainly freight trains and 2 passenger trains per day, therefore it is considered as freight case study. These freight trains could typically be organized in batteries of trains that all the group runs towards the same direction in order to increase capacity.

The maximum speed of the trains is 140 km/h.

5.6.3 General assumptions

All the trains are equipped with TIMs as in the current reference scenario.

5.6.4 Scenarios

The objective set for this line is to improve capacity, for which rolling stock, TTD and VSS conditions are defined.

The TTDs remain as they are now in the reference scenario, however, VSSs are incorporated in order to get an increase in capacity. The VSS lengths will be the ones taken from the methodolgy for reaching optimal sizes through iterations by simulations. Table 9 displays the proposed scenarios for Lérida-Reus.

Table 9: Proposed scenarios for Spanish Lérida-Reus case

Scenario	TTD	VSS	Rolling Stock
Reference	Current (ETCS Level 2)	-	Current
1	Current	From 25 m to max. TTD length	All trains with TIMs

5.7 SPAIN: CERCANÍAS BARCELONA

5.7.1 Infrastructure

For this case, one section of the Barcelona commuter network will be studied taken into account the following: El Prat de Llobregat-Paseo de Gracia (Paseo de Gracia tunnel), Hospitalet-Aragó (Plaza Cataluña tunnel) and Sagrera-Granollers (Montmeló tunnel). The reference signalling system is ETCS L2.

Figure 7 illustrates the track layout for the Hospitalet-Aragó section, a full description of this line and the others is available at [7].
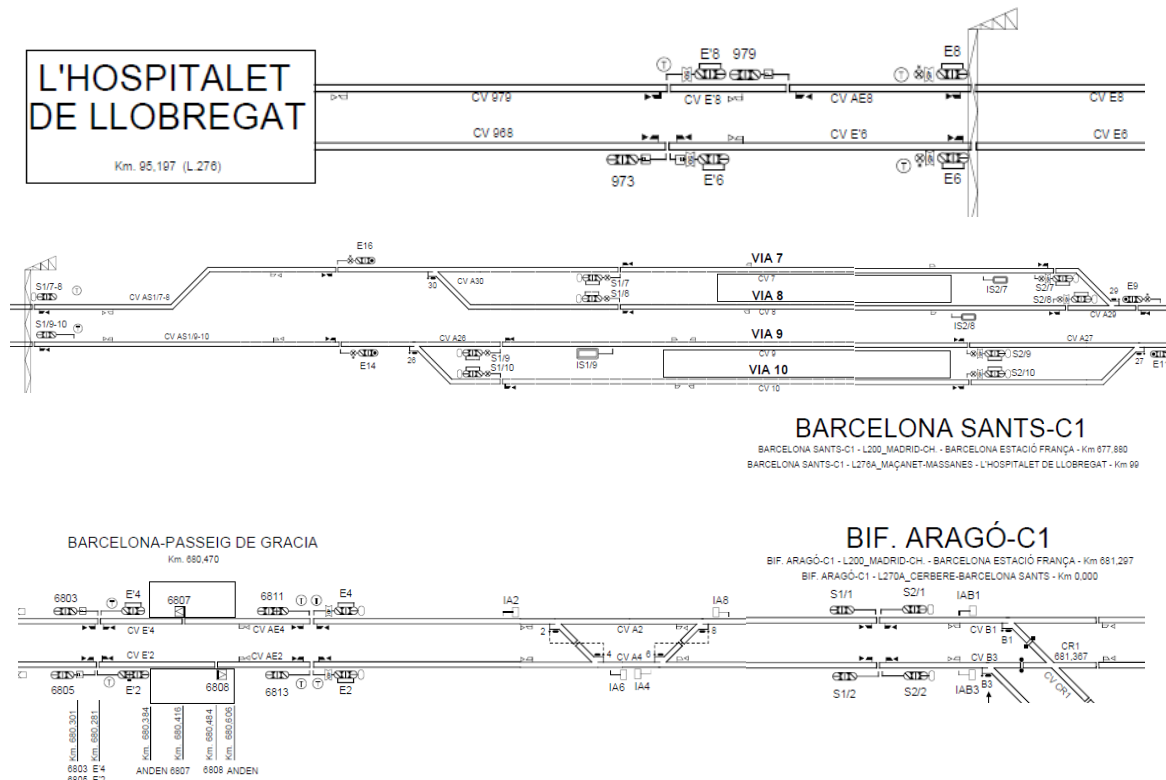
Figure 7: Section line: Hospitalet-Aragó [8]

5.7.2 Traffic

The Montmeló tunnel is a node where commuter, regional and freight trains converge.

The maximum speed of the trains is 120 km/h.

5.7.3 General assumptions

All the trains are equipped with TIMs in the reference scenario (current real situation).

TIMs conditions are changed for the rest of the simulations as explained in the Section 5.7.4.

5.7.4 Scenarios

The main objective for this line is to improve capacity, hence, conditions for rolling stock, TTD and VSS are determined.

For the rolling stock, a case where passenger trains are equipped with TIMs and freight trains are not is defined and another case where both passengers and freight trains will be equipped with TIMs is also defined. The TTDs remain as they are now in the reference scenario, however, VSSs are incorporated in order to get an increase in capacity. The VSS lengths will be the ones taken from the methodolgy for reaching optimal sizes through iterations by simulating. The proposed scenarios for the Cercanías Barcelona case study are shown in Table 10.

Table 10: Proposed scenarios for Spanish Cercanías Barcelona case

Scenario	TTD	VSS	Rolling Stock
Reference	Current (ETCSLevel 2)	-	Current
1	Current	From 25 m to max. TTD length	Passenger trains with TIMs and freight trains without TIMs
2	Current	From 25 m to max. TTD length	All trains with TIMs

Interne

5.8 FRANCE: LILLE

5.8.1 Infrastructure

This case study consists of a project for the development of the regional lines around Lille. The project is planned to be completed in 2040, and includes both capacity improvements of existing infrastructure and a new double-track line (Hénin-Beaumont – Lille) for high-speed regional trains. The new line is planned to be equipped with ETCS.

5.8.2 Traffic

The traffic of the network includes regional and suburban trains. The aim of the project is to increase traffic on all routes to/from Lille, doubling the frequencies to four trains per hour. The new Hénin-Beaumont – Lille line has a target of 12 trains per hour in each direction. It is planned to have only suburban and regional trains on the new line that will be studied. The time-distance diagram for the Lille case study is shown in Figure 8.
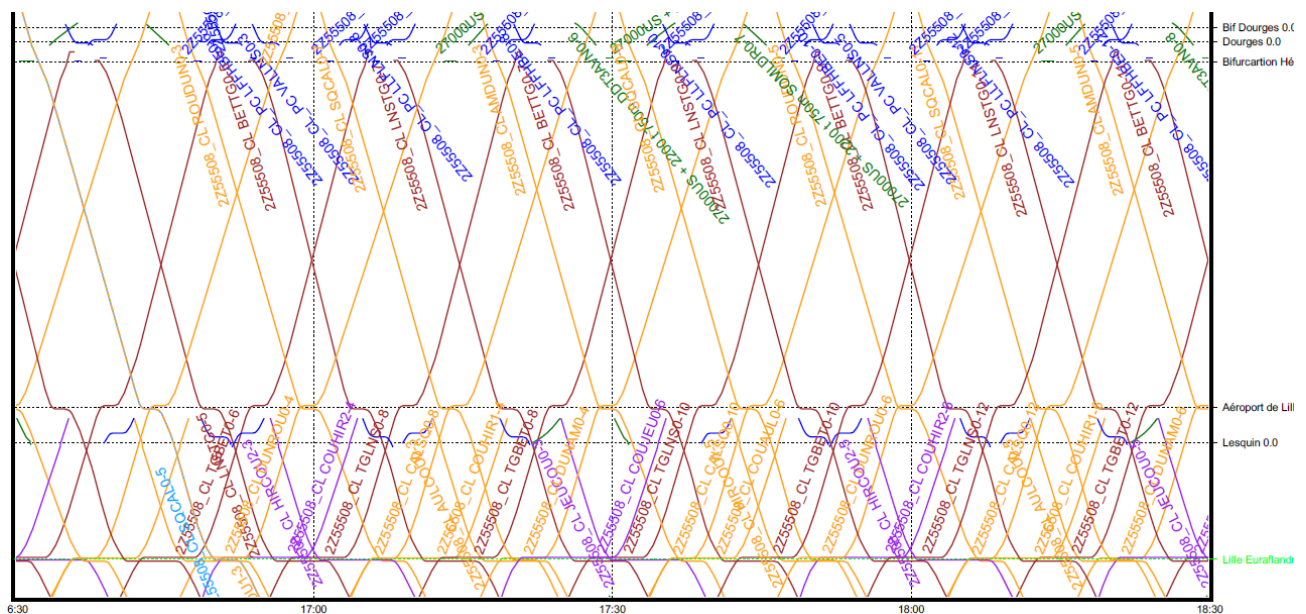
Figure 8: REHF traffic diagram, with up to 12 trains per hour, only suburban or regional trains (red and orange trains)

5.8.3 General assumptions

All trains running on the "Réseau Express Hauts-de-France, REHF", will be equipped with TIMs for the ETCS HTD scenarios.

There is currently no scheme plan that shows the division of the ETCS block sections for the line. Therefore, asumptions will be made for the division of ETCS block sections (around 1.5 km for ETCS L2 and less for ETCS HTD (length to be determined).

5.8.4 Scenarios

The aim in this case study is to determine the capacity effect of ETCS HTD compared to ETCS level 2 on the new double track line (Lille Euraflandres – Henin Beaumont). Because all trains in the network are regional and suburban, it can be assumed that all trains will either not have TIMs (the reference) or have TIMs. This gives the following proposed scenarios in Table 11.

Table 11: Proposed scenarios for French Lille case

Scenario	TTD	VSS	Rolling Stock
Reference	Current (with ETCS Level 2)	-	Current
1	Current	TBD	All trains with TIMs

5.9 FRANCE: BRETAGNE PAYS DE LOIRE (LNOBPL)

5.9.1 Infrastructure

The LNOBPL is a new proposed high-speed line in France. The aim of the project is to improve the rail connection between Brittany and Pays de la Loire. Several infrastructure improvements are proposed, including a new high-speed line, capacity treatment of critical sections of the existing infrastructure, and implementation of ERTMS/ETCS on the existing lines. Implementing HTD on new lines or on an existing line is seen as an option.

As the new high-speed line will not have a high capacity requirement, the study will focus on the existing line that are planned to be equiped with ETCS. These lines have high capacity requirement as they support mixed trafic (regional, suburban, high-speed and freight trains) The exact relevant lines of the network where the study will be carried out are still to be determined.

5.9.2 Traffic

The aim the project is to improve the frequency of the suburban, inter-regional , and high-speed links to/from Paris by increasing rail capacity and improving journey times, while supporting the development of rail freight. The traffic is mixed with high-speed train, regional trains, suburban trains and freight trains running on the sames tracks. The planned timetable for the line Rennes – Brest is shown in Figure 9.
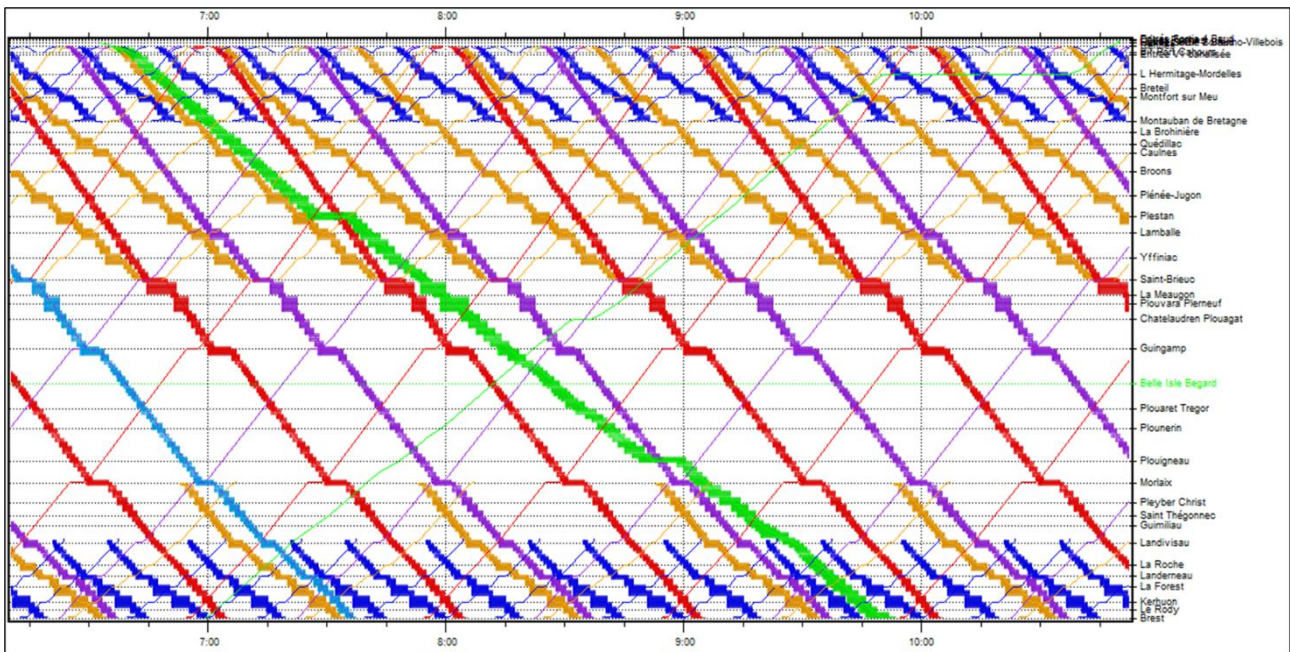

Figure 9: Example of the planned timetable for the line Rennes – Brest for 2030. Suburban train (blue), regional train (yellow), intercity train (purple), high-speed train (red), freight train (green)

5.9.3 General assumptions

All suburban and regional trains running on the network will be equipped with TIMs for the ETCS HTD scenarios.

All freight trains running on the network will not be equipped with TIMs for the ETCS HTD scenarios.

Two scenarios for the ETCS HTD will be studied for the high-speed trains :

- 1st scenario: High-speed trains equipped with TIMs.
- 2nd scenario: High-speed trains not equipped with TIMs.

There is currently no scheme plan that shows the division of the ETCS block sections for the Britany and Pays de la Loire network. Therefore, asumptions will be made for the division of ETCS block sections (around 1.5 km for ETCS L2 and less for ETCS HTD (length to be determined)).

5.9.4 Scenarios

The interest of this case study is to determine the capacity effect of ETCS HTD compared to ETCS level 2, as displayed in Table 12, where different scenarios will be compared with trains equiped or not with TIMs.

For the reference scenario, no trains will be equipped with TIMs (only ETCS L2).

For ETCS HTD, we will model a scenario with only the regional/suburban trains equiped wih TIMs and a scenario with either the regional/suburban trains and the high-speed trains equiped with TIMs.

For all scenarios, freight trains will not be equipped with TIMs. The proposed scenarios for the LNOBPL French case are displayed in Table 12.

Table 12: Proposed scenarios for French LNOBPL case

Scenario	TTD	VSS	Rolling Stock
Reference	Current design (with ETCS L2)	-	Current
1	Current	TBD	Only suburban and regional trains with TIMs
2	Current	TBD	Suburban, regional and high-speed trains with TIMs

5.10 SWEDEN: STOCKHOLM CITYBANAN

5.10.1   Infrastructure

A 6 km long commuter line through the city centre of Stockholm. The line is doubletrack with two stations on the line (Stockholm City and Stockholm Odenplan), both with platforms on the main track. No shunting is allowed at Stockholm City or Stockholm Odenplan. The tunnel is deep which means that there are high gradients at the start and end of the line, which affects the braking curves depending on down- or uphill. Gradients could also limit the possibility of VSS deployments, as it should be possible to stop and accelerate at each VSS. The current line uses track circuit for TTD. However, there are plans to change the TTDs to axle counters. The timeline is not confirmed. For the simulation of the line, the length of model should be longer than the 6 km. This is because the traffic on the connected lines will limit the possible capacity on Citybanan. The infrastructure layouts of the Stockholm Citybanan case are shown in Figure 10 and Figure 11.
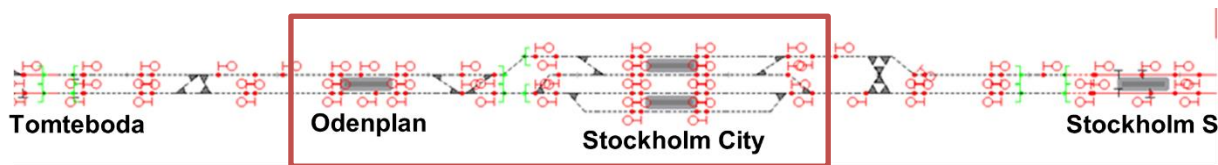
Figure 10: Citybanan Infrastructure. From connection at Tomteboda to Stockholm S, with current ATC signals (highlighted in red) [4]
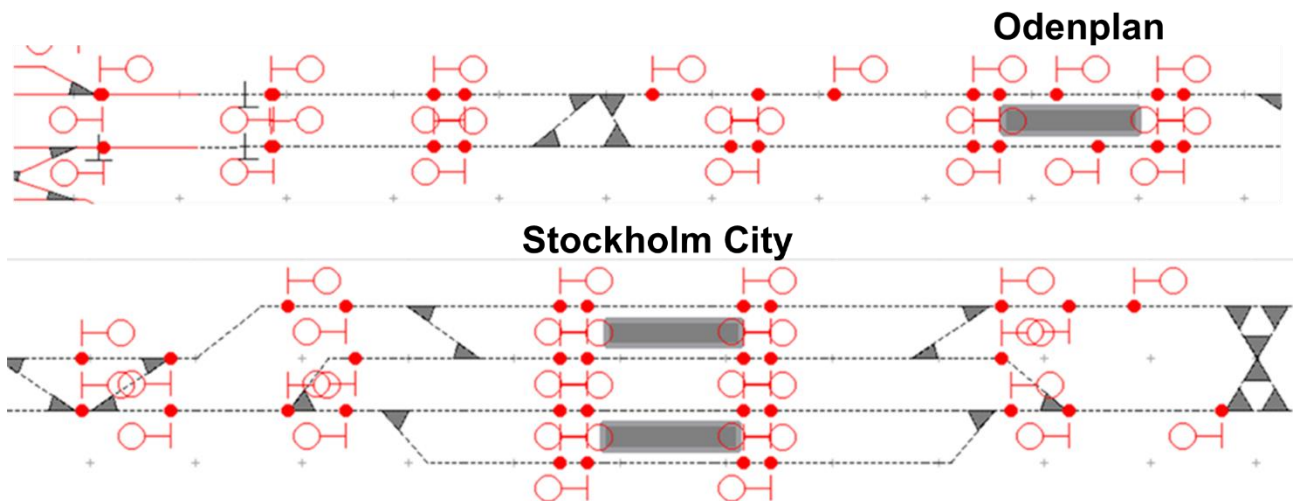
Figure 11: Zoomed-in version of Citybanan Infrastructure

5.10.2   Traffic

Traffic on the Citybanan consists of only commuter trains. The capacity consumption is high, with 392 trains/day (data from Trafikverket 2023), see Figure 12. It is also likely that there will be a need to increase the traffic in the future.

Interne

Dwell time at Stockholm City is limited to 2 min during peak traffic, and 1 min at Stockholm Odenplan. Trains also need to time the stops with platform screen doors, which can lead to extended dwell times. In some cases, trains need to reverse to align with the screen doors. Adding strain to the timetable, increasing the need for increasing the capacity, which HTD can help to alleviate.
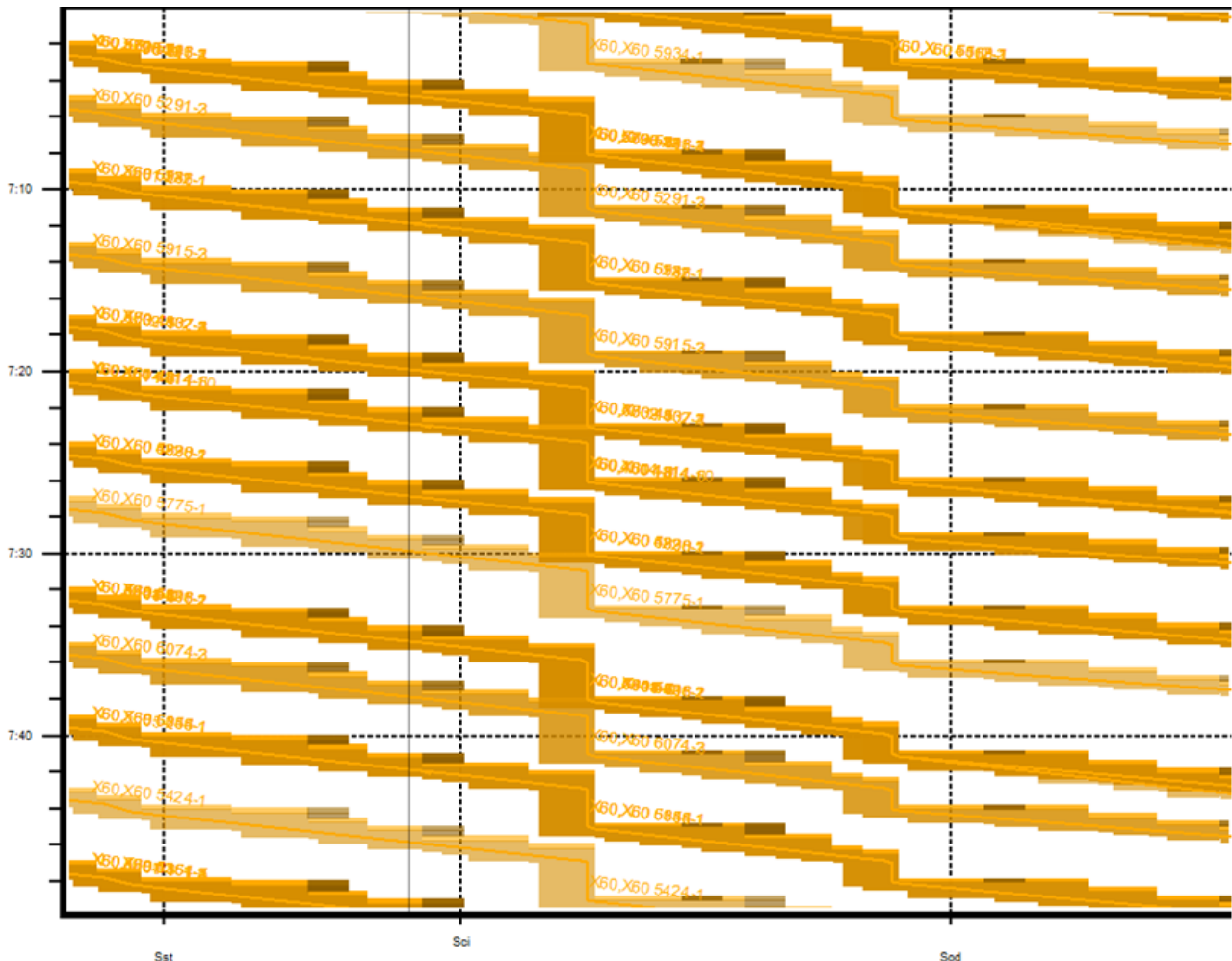
Figure 12: 2024 timetable of Citybanan [4]

5.10.3   General assumptions

For the simulations, it is assumed that all other traffic (non-commuter trains) at lines connecting to Citybanan are non-integer.

Traffic is assumed to be the same as the current timetable.

5.10.4   Scenarios

As the line has high capacity utilisation today, the performance indicator headway and the UIC-406 compression method are relevant for this case. Capacity is a prioritising criterion on this line as it is already at its limits. Robustness could be of interest. However, as trains travel on a much larger network than Citybanan, the simulated network would need to be extended. Therefore, a simulation of the extended network would be too complex for analysing capacity. The benchmark, i.e. signalling

system used as a starting point, should be ETCS L2, as the line is planned to be upgraded to ERTMS.

The specific scenarios have been chosen depending on shares of trains integrated with train integrity. Because all the trains occupying the line have the same train types, it can be assumed that there will be a migration phase (where some of the train have train integrity), followed by the entire fleet being upgraded with train integrity. The specific value of VSS should be selected with the aim of decreasing the headway. The Citybanan trains are already tightly packed, so the VSS should be as short as possible. The document ERTMS/ETCS Hybrid Train Detection: Principles [2] mentions 25 meters as an example of minimum length. However, if there are restrictions with the simulation tool (e.g., run time of the simulation), a VSS length of up to 100 meters can be accepted. We therefore propose the infrastructure and traffic scenarios as presented in Table 13.

Table 13: Proposed scenarios for Swedish Citybanan case

Scenario	TTD	VSS	Traffic
Reference	Current block lengths with ETCS L2	no	Current
1	Track circuit (extended block length) / axle counters (minimal number)	25-100 m	Current (0 % TIM equipped)
2	Track circuit (extended block length) / axle counters (minimal number)	25-100 m	Migration step (50% TIM equipped)
3	Track circuit (extended block length) / axle counters (minimal number)	25-100 m	Full deployment (100 % TIM equipped)

5.11 SWEDEN: EAST LINK

5.11.1 Infrastructure

A greenfield railway project with aim of increasing capacity between Stockholm and Linköping. Connecting to the Western Main Line at the north and to the Southern Main Line in the south. The goal of the project is for the line to become operational in 2035. The planning process is currently ongoing, and the line is planned to be doubletrack with ERTMS/ETCS Level 2. The line will have five new stations (Vagnhärad, Nyköping, Skavsta, Norrköping and Linköping) and is planned to allow train speeds of 250 km/h. The line is part of a future high-speed line in Sweden, connecting Stockholm and Gothenburg/Malmö. Between Norrköping–Linköping, the line will run parallel with the current Southern Main Line (see Figure 13).

Figure 13: East Link. Red lines indicate the new line between Järna and Linköping. Grey line is the previous track

5.11.2 Traffic

The traffic projects of the lines are defined for 2045 [11]. Regional trains: Järna–Nyköping, 34 trains (2 trains peak hour); Nyköping–Norrköping, 32 trains (2 trains peak hour); Norrköping–Linköping, 30 trains (2 trains peak hour). Long-distance: Järna–Linköping, 47 trains (4 trains peak hour).

5.11.3 General assumptions

There are no general assumptions to be described for this case-study.

5.11.4 Scenarios

As the line is a greenfield project, it is of interest to study various lengths of VSS. Only trains running at high speeds will operate on the line, so all trains are assumed to have TIMs. The proposed scenarios for the East Link are shown in Table 14.

Table 14: Proposed scenarios for Swedish East Link case

Scenario	TTD	VSS	TIMs
Reference (ETCS L2)	Current	-	-
1	Current	TBD	All trains with TIMs

5.12 SWEDEN: SOUTHERN MAINLINE (NORRKÖPING – MJÖLBY)

5.12.1 Infrastructure

The section Norrköping–Mjölby is part of the Southern Mainline between Stockholm and Malmö, one of the most important railway connection in Sweden. The section between Norrköping–Mjölby is about 79 km long, double track and electrified. The Southern Mainline infrastructure is illustrated in Figure 14. The allowed speed on the section is between 110–200 km/h. The section consists of seven stations, where two stations (Linghem and Kimstad) have platforms on the main track and no possibility for overtaking.
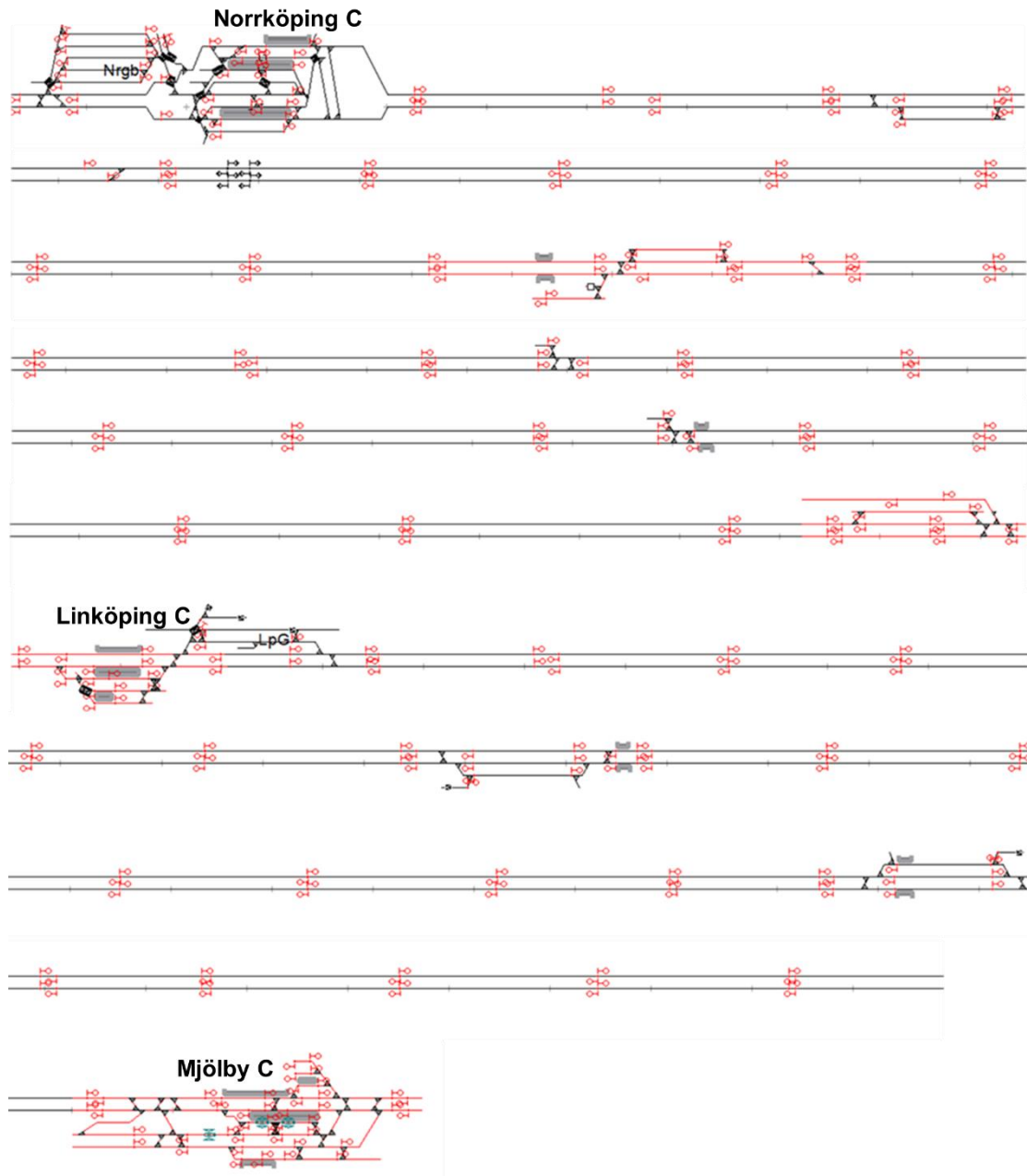
Figure 14: Southern Mainline infrastructure. Section Norrköping to Mjölby, with current ATC signals (highlighted in red)

5.12.2   Traffic

The traffic on the section Norrköping–Mjölby (Table 15) consists of freight, long-distance and regional trains. There is a high degree of speed difference of the train types. Long-distance trains have an allowed speed of 200 km/h, regional trains of 160 km/h, and freight trains of 100 km/h.

Table 15: Current traffic volume for the section Norrköping - Mjölby

Trajectory	Long-distance trains	Regional trains	Freight trains
Norrköping – Linköping	43	48	8

Linköping – Mjölby	21	48	10

5.12.3 General assumptions

Traffic is assumed to be the same as the current timetable.

5.12.4 Scenarios

Performance indicators of specific interest for the Southern Mainline are headway, the UIC-406 compression method and recovery time. The reason is that capacity and robustness are important aspects of this line, as the capacity utilization is high, and the line is prone to disturbances. The signalling system ETCS L2 is used as benchmark, as there is an ongoing project to implement ERTMS on the line.

The traffic scenarios have been chosen from the assumption that different train types will be upgraded with train integrity in steps, from easy implementation to complex. For this reason, it is assumed that railcars will have working train integrity in a first step, followed by locomotive-hauled passenger, and lastly freight trains. The value for VSS lengths in this case study should be from the assumption of a simple deployment strategy. Meaning, that the VSS lengths have a standardized length. This is mainly because of two reasons: firstly, it simplifies the simulations in this first step of studying the deployment strategies; secondly, studying the effect of a standardized length could be of interest as it would save cost for the HTD deployment project. A standardized VSS length, in this step, should be in the range of 200 – 500 meters. The reason for this is that similar values have been used in earlier studies [12].

The total number of scenarios to be simulated for the Swedish Southern mainline is 16 (four train integrity scenarios per infrastructure scenario). The scenarios for the implementation of virtual blocks and the extension of current blocks are reported in Table 16.

Table 16: Proposed infrastructure scenarios for Swedish Southern mainline case

Scenario	TTD	VSS
Reference	Current block lengths	no
I-1	Current block lengths	200-500 m
I-2	Track circuit (extended block length)/axle counters (minimal number)	no
I-3	Track circuit (extended block length)/axle counters (minimal number)	200-500 m

The suggested scenarios regarding the implementation of train integrity are provided in Table 17.

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Table 17: Proposed train integrity scenarios for Swedish Southern mainline case

Scenario	Railcar	Locomotive-hauled passenger trains	Freight trains
Reference	No TIM	No TIM	No TIM
T-1	TIM	No TIM	No TIM
T-2	TIM	TIM	No TIM
T-3	TIM	TIM	TIM

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5.13 THE NETHERLANDS: SAAL-CORRIDOR (SCHIPHOL AIRPORT, AMSTERDAM, ALMERE, LELYSTAD)

The SAAL-corridor is one of the busiest railway lines in the Netherlands on which a capacity increase is planned by implementing ETCS L2. From Schiphol airport, the line runs to the intercity station of Amsterdam Zuid, then via Weesp to Almere and ends in Lelystad. The line contains multiple locations where traffic merges and diverges to other corridors.

In this section, we describe the infrastructure scenarios and traffic scenarios for the SAAL corridor. Next, we elaborate on several assumptions that are relevant for the Netherlands. Finally, we describe which simulations are to be executed.

5.13.1 Infrastructure

The infrastructure consists of several parts of 4-track. These sections lie between Hoofddorp, Schiphol and Amsterdam Zuid and around Weesp. Furthermore, the stations of Rai, Weesp, Almere Centrum, Almere Oostvaarders and Lelystad Centrum provide more than 2 platform tracks. The rest of the line is all double track.

The reference infrastructure scenario is the base infrastructure on which a Level 2 design from the real project is assigned according to design version 2.0 of February 2024. We will vary two infrastructure design parameters in order to find the ideal design principle under various conditions of usage.propose 7 different infrastructure scenarios, based on variations around two parameters to find the proper design principles for various usage of the:

1. Number of axle counters
2. Distance of virtual blocks
3. Based on these two parameters we have created seven infrastructure design scenarios that will be described below.

The number of TTD blocks can be varied in 3 gradations:

1. The base infrastructure on which a Level 2 design from the real project according to design version 2.0 of February 2024. This is infra scenario **I-0**.

2. The first HTD design, numbered **I-1**, is based on the base L2 design of I-0 and assumes a headway of approximately 1 minute without buffer times still reachable on the TTD for degraded situations and behind trains without TIM. This leads to a reduction of 50 % axle counters as a result of the following assumptions:

   - Physical blocks of ~ 2 km on tracks without regular freight traffic, given passenger trains running at 140 km/h

   - Physical blocks of 0,5 – 1 km on tracks with regular freight traffic, given freight trains running at 100 km/h

   - Some shorter physical blocks near stations

   - No additional virtual blocks

3. The second HTD-design, numbered **I-4**, is the base infrastructure with only a minimum number of axle counters, always near other physical objects (switches and level crossings).

This leads in the worst case to trains running only at station distance in degraded situations or behind trains without TIM.

The distance of virtual blocks can be varied in 2 gradations:

- The base infrastructure from scenario I-1 or I-4 with additional virtual blocks to further optimise capacity. The virtual blocks are 200-250 meters apart (usually by splitting the designed TTD-blocks in 2 VSS). This fits to a headway of approximately the timetable resolution of 6 s for the shortest and fastest trains. These scenarios get the numbers **I-2** and **I-5**.

- The infrastructure from scenarios I-2 and I-5 with additional virtual blocks to further optimise capacity. The virtual blocks are 100-125 meters apart. This fits to a headway of approximately half the timetable resolution of 3 s for the shortest and fastest trains. These scenarios get the numbers **I-3** and **I-6**.

This leads to the total of 7 infrastructure scenarios, numbered I-0 to I-6, as shown in Table 18.

Table 18: Overview of infrastructure scenarios for the Dutch SAAL case

	Increasing number of virtual blocks →			
Decreasing umber of trackside based blocks ↓	I-0 Reference (ERTMS L2)	x	x	x
	I-1S Medium number axle counters, same virtual blocks as reference	I-1F Medium number axle counters, same virtual blocks as reference	I-2 Medium number axle counters, virtual blocks every 200-250m	I-3 Medium number axle counters, virtual blocks every 100-125m
	I-4S Minimum number axle counters, same virtual blocks as reference	I-4F Minimum number axle counters, same virtual blocks as reference	I-5 Minimum number axle counters, virtual blocks every 200-250m	I-6 Minimum number axle counters, virtual blocks every 100-125m
Area to simulate	Complete SAAL area	Only "Flevo" line		

In order to find a balance between workload and the demand for simulations we propose to simulate all scenarios in which the distance between virtual blocks are varied only on the "Flevo" line between Muiderberg Aansluiting and Lelystad (note that the Flevo Line is the northeastern part of the SAAL area). This leads to infra scenarios I-1 and I-4 having a version on the whole scope of SAAL and on the scope of only the Flevo line. These infra scenarios are marked with S and F respectively. The

reference I-0 is only analysed for the whole SAAL area and the infra scenarios I-2, I-3, I-5 and I-6 are only analysed for the smaller Flevo area.

Direct comparison is possible between infra scenarios in every column [I-0, I-1S and I-4S], [I-1S and I-4S], [I-1F and I-4F], [I-2 and I-5] and [I-3 and I-6] and in every row [I-1F, I-2 and I-3] and [I-4F, I-5 and I-6], where within each group the geographical area is the same and is only varied in one layout setting, either the number of axle counters or the number of virtual blocks. The design of the Flevo Line for the infrastructure scenarios I-0 and I-1 are displayed in Figure 15 and Figure 16, respectively.
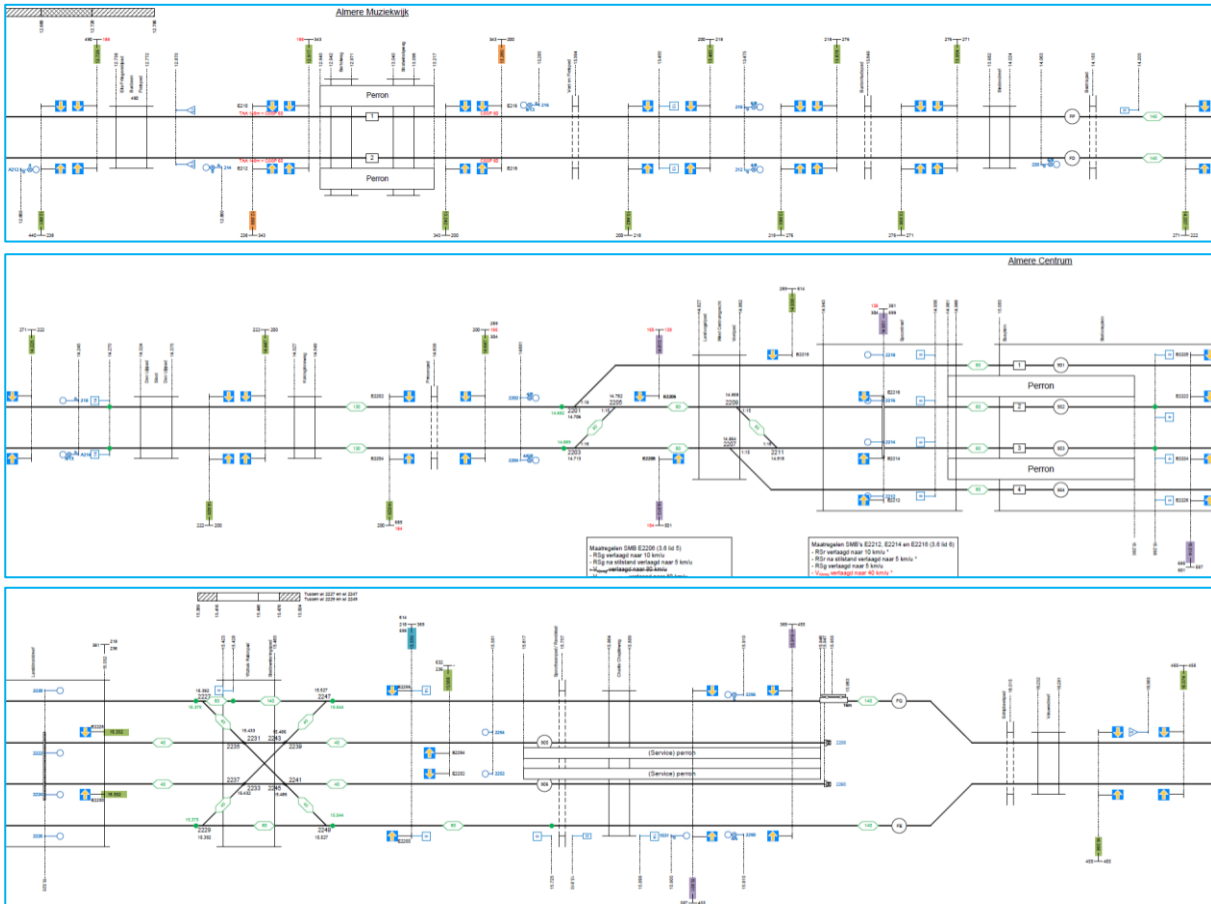

Figure 15: ETCS L2 design for part of the Flevo Line between Almere Muziekwijk and Almere Centrum according to infra scenario I-0
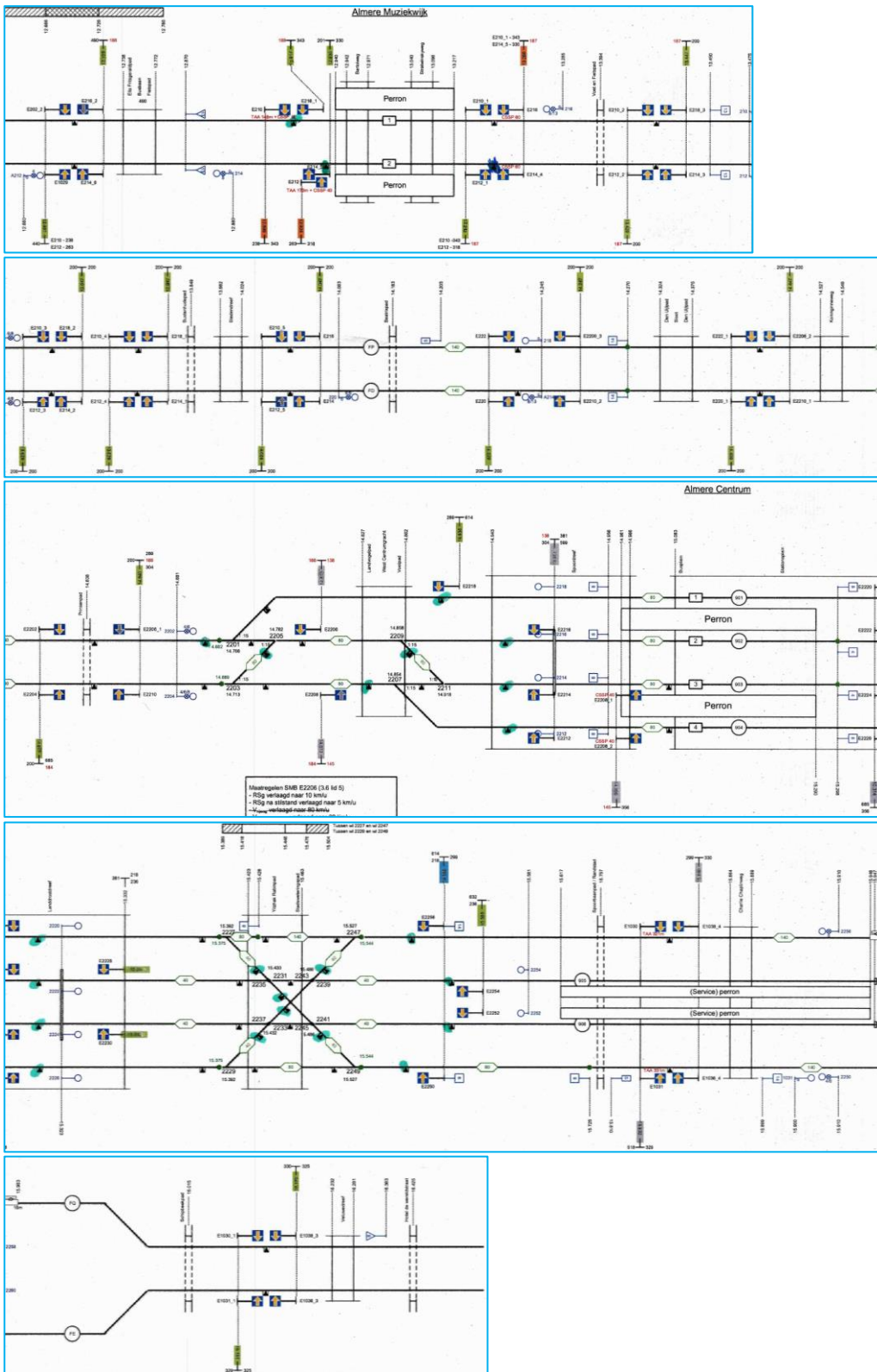
Figure 16: ETCS HTD design for part of the Flevo Line between Almere Muziekwijk and Almere Centrum, based on the ETCS L2 design, where the green marked axle counters should remain. Other axle counters are replaced by VSS, according to infra scenario I-1.

5.13.2 Traffic

The SAAL-corridor contains high density mixed traffic of intercities and regional trains in an hour-pattern, including two international paths and two freight paths. In Figure 17, the line plan is described. Between Schiphol and Lelystad, and between Schiphol and Hilversum, an intercity service runs every 15 minutes. Furthermore, there are 6 Sprinters an hour between Almere and Amsterdam Centraal, 4 Sprinters between Hilversum and Amsterdam Centraal and 2 Sprinters between Hilversum and Almere. Finally, 4 Sprinter trains run from Amsterdam Zuid to Lelystad that do not stop at local stations between Weesp and Lelystad.

Freight paths are also part of this corridor and run twice every hour between Amsterdam Bijlmer and Hilversum. International paths are part of regular intercity traffic on this corridor. One of the four intercities to Lelystad runs from Brussels, and one of the intercities to Amersfoort continues to Berlin. In this study, these trains are considered as regular national intercities.

The intercities run in a strict 15-minute interval, while all other trains are evenly divided in this interval. This leads to multiple short headways. Between Schiphol and Amsterdam Zuid a train runs every 2.5 - 3 minutes without exception. The most restricting part of the OV-SAAL network is between Weesp and Almere. This time-distance diagram is visualized in Figure 18, in which the intercities are shown in blue. The local trains from Amsterdam Zuid run non-stop between Weesp and Almere. Together with all Sprinters, the structure is described from Weesp to Almere as follows: Intercity, local train from Amsterdam Centraal, local train from Amsterdam Zuid, local train from Amsterdam Centraal or Hilversum, Intercity. Almost all headways on Weesp and Almere are planned at 2.5 minutes.
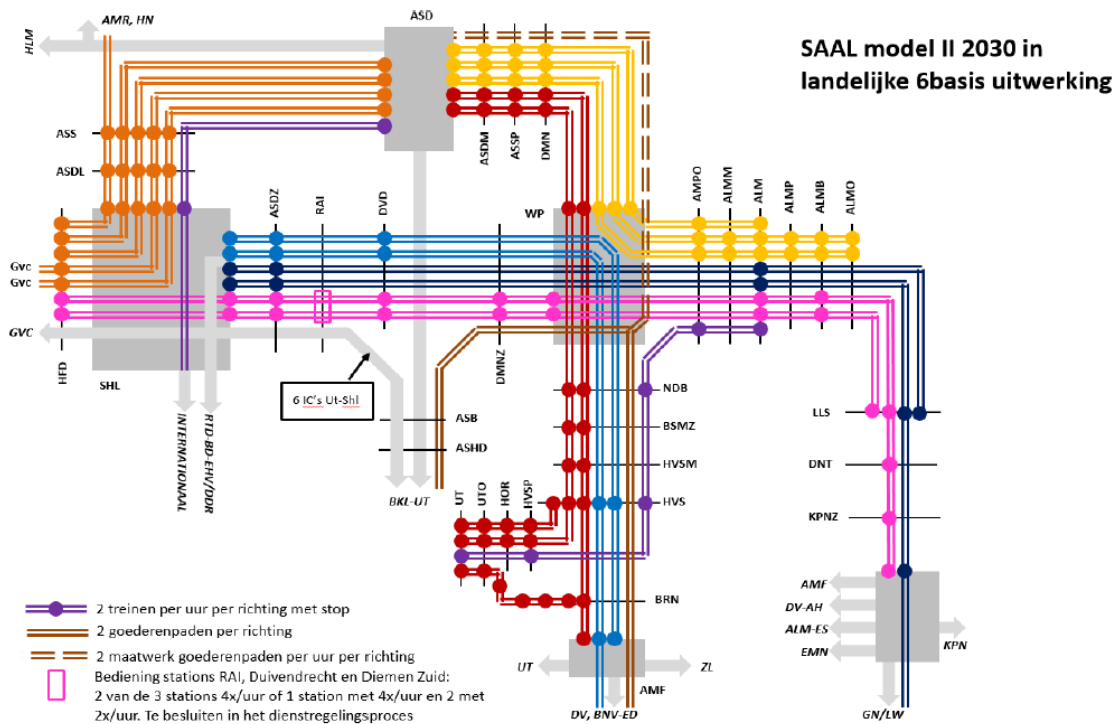

Figure 17: Line plan of OV-SAAL. In dark blue and light blue: Intercities, in red, pink, purple and yellow: Sprinters
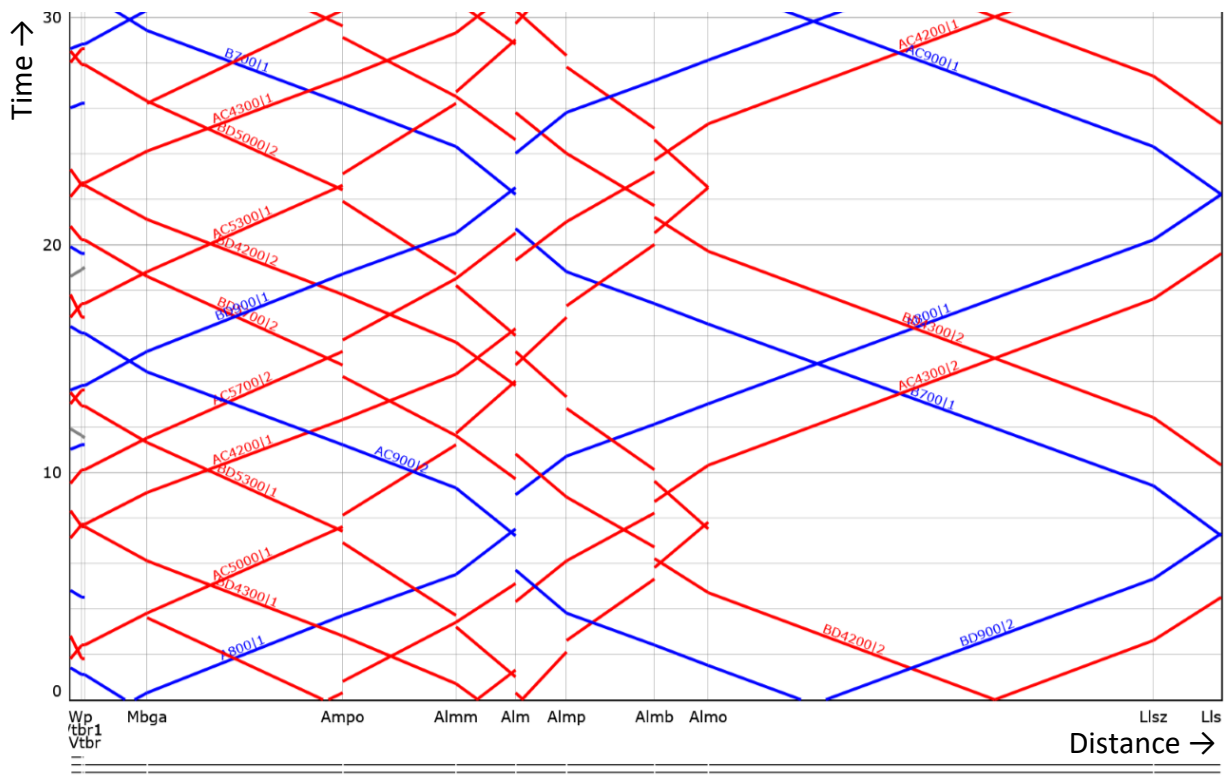
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Figure 18: Time-distance diagram of SAAL timetable between Weesp and Lelystad. In red: Sprinters, in blue: intercities

5.13.3   General assumptions

There are several assumptions specific for the Dutch network that are described in this section. All of these are used to increase the applicability for the Dutch system.

The rolling stocks we use for passenger trains are ICNG-13 (Intercity Nieuwe Generatie) for all intercities in Flevoland and Hilversum, and SNG-10 (Sprinter Nieuwe Generatie) for all local trains and express trains.

Running time supplements are applied in the timetable, and therefore need to be incorporated in the simulation as well. The running time supplement is described as a percentage of the technical running time. The OV-SAAL timetable uses 7% for all intercities, and 6% for all local trains and express trains.

A buffer time of 60 seconds is applied to all passenger trains. This practically means that every section is occupied 60 seconds after a train has left that specific section. We use this method on all scenarios. This value is used in order to have an additional buffer between two trains in the timetable for the purpose of robustness, when they have to occupy the same infrastructure shortly behind each other.

The freight paths we consider run from Kijfhoek, through Weesp to Amersfoort and further, in both directions. These trains have a length of 720 metres, carry 2400 tonnes and are propelled by one BR189. Freight trains do not run with a running time supplement and do not use a buffer time.

We consider two types of dwell time. The first is the dwell time at small stations. On these, local trains will dwell for 30 seconds and intercities dwell for 54 seconds. Those are the technical minimum dwell time based both on realisation data and proces analysis of the dwell procedure. On larger stations, a larger value is used based on both realisation data and robustness measures. We use a list made by ProRail that includes all intercity stations and differs for Sprinters and Intercities.

5.13.4 Scenarios

We propose 7 timetable scenarios numbered with "T-" to assess the impact on capacity and robustness. The scenarios outlined in Table 19 are based on the areas to simulate specified in Table 18. Scenarios T-1 and T-3 are analysed for both the SAAL corridor and the Flevo Line, whereas T-2 is analysed exclusively for SAAL. Scenarios T-4, T-5, T-6, and T-7 are analysed solely for the Flevo Line. The combination of the infrastructure scenarios and timetable scenarios lead to 31 combinations as depicted in Table 19. In all timetable scenarios except for T-3 the assumption is that all regular passenger trains have a TIM.

Table 19: Description of timetable scenarios and related infra scenarios for the SAAL case

Nr	Infra scenarios	Description
T-1	All 7	Regular timetable without freight trains
T-2	I-0, I-1S, I-4S	Regular timetable including freight train paths numbered AB10 and KBG10
T-3	All 7	Sprinters that do not include a TIM. We choose Sprinters instead of intercities because Sprinters are more constricting in the timetable
T-4	I-1F, I-2, I-3, I-4F, I-5, I-6	Regular timetable including a freight train on a detour route
T-5	I-1F and I-4F	Regular timetable including a non integer train (i.e. an open access train) on detour route
T-6	I-1F, I-2, I-3 *	Regular timetable (without a freight train on a detour) in which 1 train has an unplanned stop for 15 minutes. **
T-7	I-1F, I-2, I-3 *	Regular timetable (with a freight train on a detour) in which 1 train has an unplanned stop for 15 minutes. **
*) For these scenarios the three performance indicators for delayed situations will be used.		
**) 15 minutes, because of the 15-minute pattern of SAAL.		

6   CONCLUSIONS

The goal of this deliverable is to describe the test specification requirements for ERTMS/ETCS Hybrid Level 3 (HL3), also known as Hybrid Train Detection (HTD), to be considered in EU Rail FP1 WP8 and of which the capacity and robustness effects according to the specified performance indicators will be calculated in EU Rail FP1 WP9. The methodology, case studies and scenarios have been reviewed by partners from EU Rail FP1 WP8, that are now making preparations to execute the required scenarios for WP9.

The scenarios are provided for seven Spanish case studies, two case studies in France, three in Sweden and one in the Netherlands. The Spanish cases cover all five market segments: high-speed, mainline (mixed traffic), (sub-)urban, regional and freight. They are exploratory of the headway performance indicator. The insights can be used further in the French, Swedish and Dutch cases, that cover the high-speed, mainline (mixed traffic) and (sub-)urban market segments. They use also relative capacity utilisation as a measure in order to evaluate the capacity from a line and network perspective. Finally, two cases from Sweden (Southern mainline) and the Netherlands (SAAL-corridor) will be used to evaluate HTD-designs for their robustness by adding a deterministic delay to a single train. This is measured by the performance indicators: recovery time, number of affected trains and total delay in the system.

The scenarios are built specifically around logical combinations of infrastructure and traffic. In the infrastructure, the variance lies in the number and positioning of trackside train detection and the virtual subsections in between. In the traffic the variance is possible in the share and types of trains that are equipped to fully utilise HTD by having a Train Integrity Monitor on board.

The results of the calculations of EU Rail FP1 WP9 will be used in the development and evaluation of the method for track layout with ETCS HTD, that will be described in deliverable 37.2 of this work package. Another evaluation of the results will be performed in EU Rail FP2 WP32, where different DATO-concepts are compared.

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